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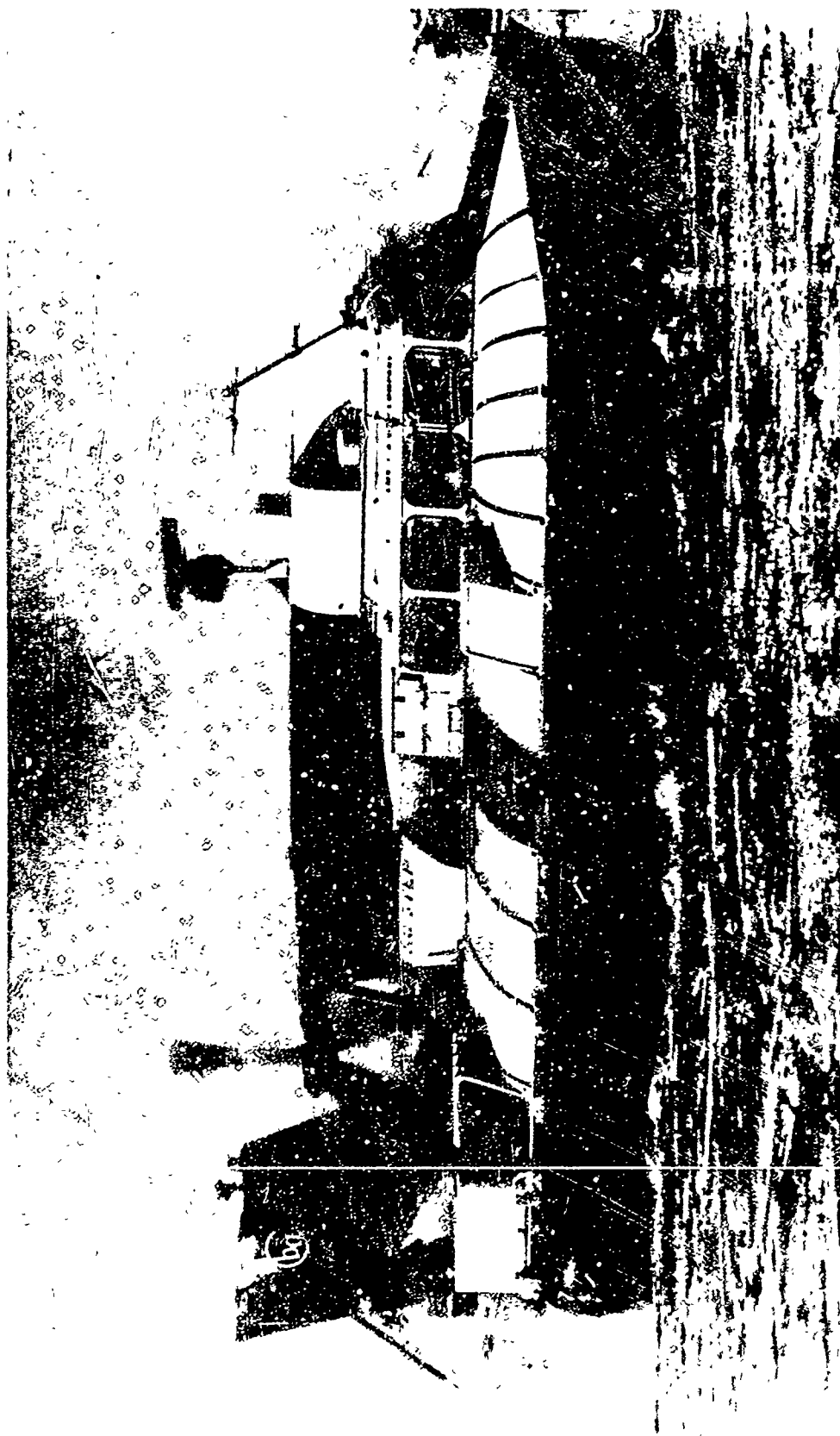
FOREWORD

The Quarterly Bulletin is designed primarily for the information of Canadian industry, Universities, and Government Departments and agencies. It provides a regular review of the interests and current activities of two Divisions of the National Research Council:

The Division of Mechanical Engineering
The National Aeronautical Establishment

Some of the work of the two Divisions comprises classified projects that may not be freely reported and contractual projects of limited general interest. Other work, not generally reported herein, includes calibrations, routine analysis and the testing of proprietary products.

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HOVERCRAFT PROCEEDING OVER ICE WITH STERN-MOUNTED ECHO SOUNDER
IN RAISED POSITION

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OCEAN WAVE PROFILE AND SPECTRA MEASUREMENT USING AN AIRBORNE MAGNETOMETER

R. Baker* and P.W.U. Graefe**

1.0 INTRODUCTION

The movement associated with ocean waves of conductive sea water interacts with the ever present earth's magnetic field to produce circulating electric eddy currents. To see how this is accomplished let us refer to Figure 1, which shows a sinusoidal wave travelling with velocity v from left to right. Instantaneous particle velocities at various locations in the wave are shown. Owing to the earth's magnetic field B , currents proportional to $v \times B$ are induced in the water, as shown in the Figure. These currents flow into the paper below the crests of the waves, and out of the paper below the troughs of the waves. These eddy currents in turn will set up magnetic fields that will be seen to reinforce the earth's magnetic field on the leading edge of the wave and oppose the earth's magnetic field on the trailing edge of the wave, the total field variation along the direction of wave propagation being sinusoidal for a sinusoidal water wave.

This change in the earth's magnetic field, which is due to the wave motion, can be detected by floating, submerged, or airborne magnetometers.

Weaver (Ref. 1) describes a method for calculating the magnetic field of ocean waves, and measurements corroborating Weaver's approach, both at the surface and under the sea, have been made by Fraser (Ref. 3) and Maclure et al. (Ref. 2). Our work tends to confirm Weaver's calculations above the sea surface.

For various wave periods T , Figure 3 shows the amplitude of the magnetic field component h parallel to the ambient earth's magnetic field H_e , with dip angle I , at an altitude s produced by a sinusoidal wave component of amplitude a , heading θ , and angular frequency ω in water of conductivity σ , where g is the acceleration of gravity. Figure 3 has been calculated from Weaver's equation

$$h = \left[\frac{\pi a \sigma H_e g}{\omega} \right] \left[\sin^2 I + \cos^2 I \cos^2 \theta \right] e^{-\frac{s \omega^2}{g}} \quad (1)$$

which is an approximation that is good for wave periods of 60 seconds or less.

2.0 OCEAN WAVE MAGNETIC FIELDS OBSERVED BY AN AIRBORNE MAGNETOMETER

In measuring the magnetic fields of ocean waves with a moving airborne

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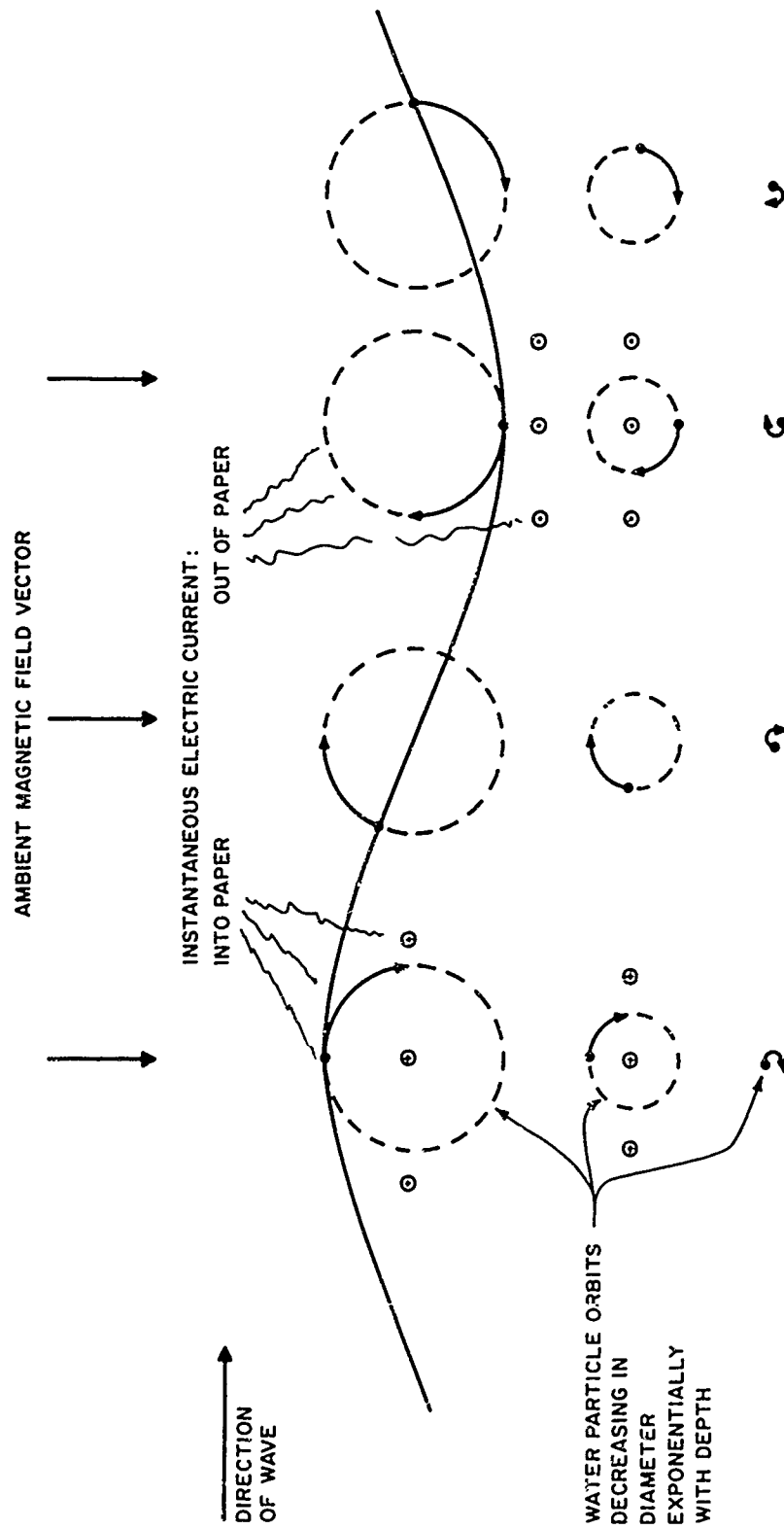


FIG.1: ELECTRICAL CURRENTS INDUCED BY WAVE MOTION

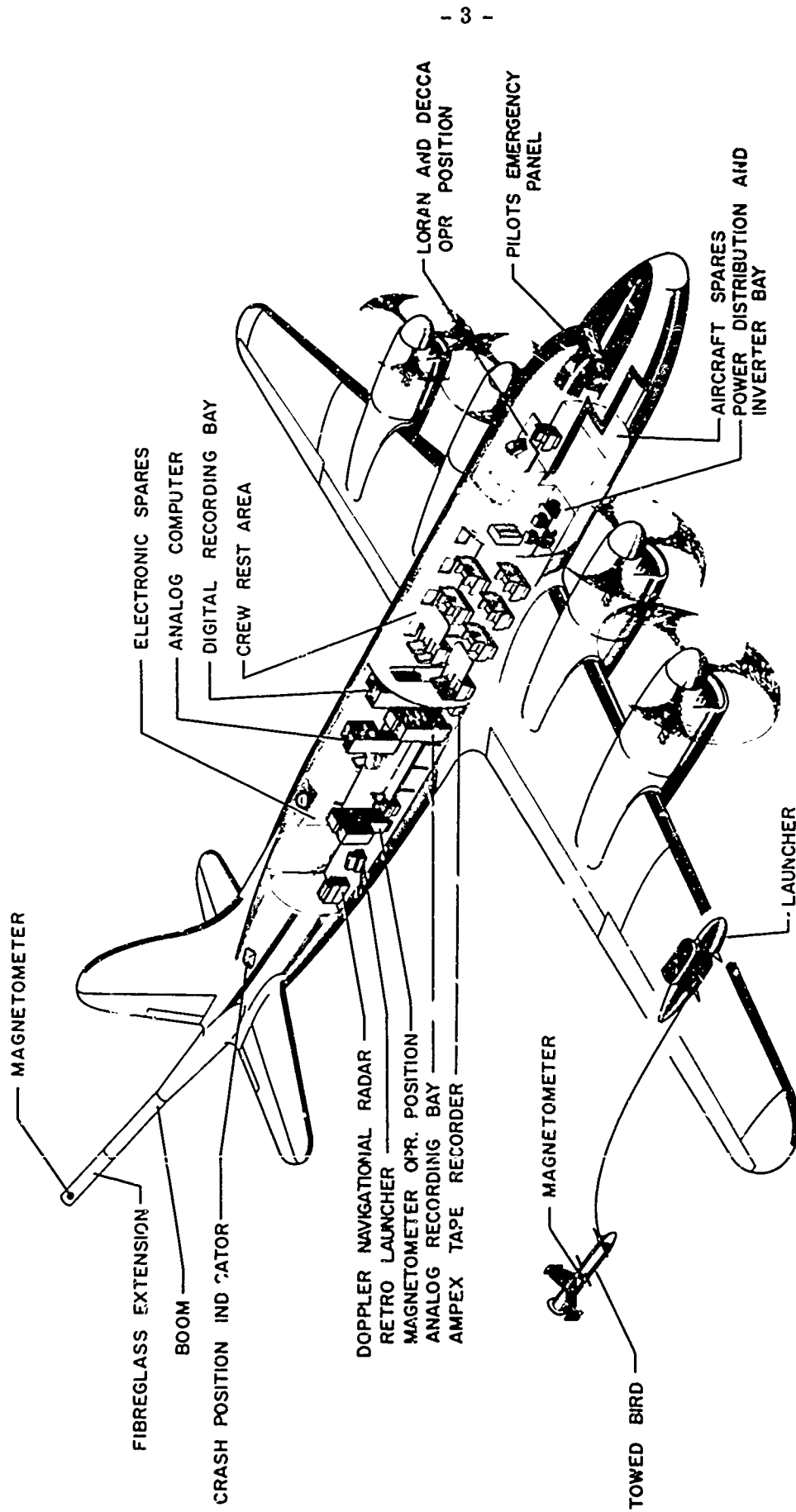


FIG. 2: CUTAWAY DRAWING OF MAGNETOMETER EQUIPPED AIRCRAFT

magnetometer, several characteristics of wave motions and of the resulting magnetic fields must be considered. Since the velocity and wavelength of a given component wave is a function of the wave period, the apparent frequency of the magnetic signal seen by the airborne magnetometer will depend upon the velocity and wavelength of the wave and the velocity and relative heading of the aircraft. The amplitude of the magnetic signal seen by the aircraft will depend only on equation (1), which is plotted for a family of component wave periods in Figure 3.

Since in the propagation of surface gravity waves the ocean is dispersive, the phase velocity of each component wave is a function of the wave period or frequency. We have assumed that

$$v = \frac{g}{2\pi} T \quad (2)$$

where v is the component wave phase velocity in meter second⁻¹, g is the acceleration of gravity in meter second⁻² and T the wave period in seconds. This may be rewritten

$$v = 3.03T \text{ knots} \quad (3)$$

or
$$v = 1.56T \text{ meter second}^{-1} \quad (4)$$

The wavelength is also dependent on period according to the relation

$$L = \frac{g}{2\pi} T^2 \quad (5)$$

which can be rewritten

$$L = 1.56T^2 \text{ meters} \quad (6)$$

where 3, 4, and 6 assume that T is in seconds and $g = 9.80 \text{ meter second}^{-2}$.

As examples of the effect of this dispersion on the signal seen by an airborne wave profiler, consider an aircraft heading directly against oncoming waves at a speed of approximately 180 knots. Waves with actual period 10 seconds, $L = 156$ meters, will have a phase velocity of approximately 30 knots, an apparent velocity of 210 knots, and an apparent period of 1.4 seconds; 20-second waves with $L = 624$ meters, phase velocity 60 knots, will have an apparent velocity of 240 knots, and apparent period of 5.0 seconds; 30-second waves with $L = 1404$ meters, velocity 90 knots, will have an apparent velocity of 270 knots, and an apparent period of 10 seconds. The situation will be different if the aircraft does not fly directly "upwave"; for all other headings the waves will have lower apparent velocities and longer apparent periods.

In the unlikely case that only one wave component is present, the heading of

Spinner et al.¹⁰⁾ are $K = 0.947$ for a circular cross section and $K = 0.865$ for a rectangular cross section. These values differ from those proposed by the writer³⁾ by 7 percent and 2 percent respectively.

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the wave might be found by flying several short lines on different headings at constant speed-made-good over the water. When the highest frequency is recorded it may be assumed that the waves are heading opposite to the aircraft direction. Actual wave period can then be calculated if the apparent period and aircraft speed are known. In some cases it is possible to determine true wave frequencies and headings in a mixed sea with waves travelling in different directions.

If waves were conserved and infinitely crested, a particular heading and speed of the aircraft could provide a component of velocity in the direction of the wave that equalled wave velocity, and no change in wave height (or magnetic signal) would be observed. In practice, of course, waves are not conserved, the crests are always finite, and therefore some finite frequency signal will be observed on any heading.

In the more general case when more than one frequency wave component is present the magnetic data can yield correct wave period and amplitude results if all of the component waves present are heading in the same direction. At first glance there appears to be a risk of complex vector addition of the magnetic fields of the various frequency components that could upset the usual assumptions of linearity required in a wide band spectral analysis.

Since the magnetic fields produced by the waves are small, 1.0 or 2.0 nT compared with the ambient earth's magnetic field of 20,000 to 70,000 nT, only that component of the ocean wave magnetic field parallel to the ambient field will be detected. Magnetic fields of several nT perpendicular to the ambient field will not alter the total field to a resolution of 10^{-4} nT, well below the resolution now possible. The detected magnetic field change due to any given wave component is thus independent of the presence or absence of any other wave component. This would not be true if the magnetic fields produced were significant compared with the ambient field.

3.0 NOISE SOURCES

It was our expectation that existing airborne magnetometer systems, and in particular the system available to us (Fig. 2) would permit measurement of the spectrum of surface waves with actual periods between 10 and 30 seconds. This system provides a peak-to-peak noise level below 0.03 nT in the pass band 0.10 to 1.0 Hz when travelling at speeds near 160 knots at low levels over relatively deep water. Below 0.1 Hz, magnetic noise due to micropulsations and aircraft motions becomes significant. Since the signal resulting from ocean waves increases inversely with frequency, special filters could probably permit detecting waves with longer periods than 30 seconds. To detect waves with periods shorter than 10 seconds would require that the filter be opened above 1.0 Hz and, further, that the noise level be considerably better than 0.03 nT at these frequencies.

Vertical motion of the aircraft in the natural vertical gradient of the earth's magnetic field typically produces a signal of 0.01 nT for each foot of vertical displacement. For 20-second waves with a magnetic field of amplitude 0.4 nT for waves of 1.0 foot amplitude, vertical motions are not a limiting factor. For 5.0-second waves producing only 0.001 nT for waves 1.0 foot in amplitude, control or measurement of aircraft vertical motion becomes the critical and limiting factor. On the other hand 50-second waves, if they exist at all, would produce 0.10 nT for each 0.75 inch of wave height.

The geology of the ocean bottom is usually magnetic and produces magnetic anomalies with wavelengths of the same order as the aircraft-to-source separation. Waves with period 30 seconds, wavelength 1400 meters, are not likely to be discernible in continental shelf areas where the sea is 200 meters or less in depth, but should be readily detected in deep ocean regions.

The major sources of noise, geology, micropulsations, and uncompensated aircraft vertical motions, produce the largest magnetic noise at low frequencies, and for this reason all analogue data must be pre-filtered with steep roll-off high pass filters. Sample analogue recordings of the magnetic data, filtered to remove low frequency noise, are shown in Figure 4 for various aircraft altitudes.

The magnetic fields of internal waves have not been calculated or considered. If such waves produce significant magnetic signals, they may be detectable by this technique or, alternatively, may be a confusing source of noise.

4.0 EXPERIMENTAL OBSERVATIONS

All of the magnetic measurements presented in this paper were made using the airborne magnetometer system shown in Figure 2. The magnetometer used is a continuously servo-orienting rubidium vapor self-oscillator with a useful in-flight resolution and noise level better than 0.01 nT peak-to-peak. An early version of this magnetometer is more fully described by Baker and Davis (Ref. 6).

Attempts were made to compare the airborne data with wave height measurements made by conventional methods at the sea surface. From data taken March 1, 1967, Figure 5 compares the magnetic spectrum measured in flight at 100 feet with the equivalent magnetic spectrum calculated from the wave amplitude power spectral density obtained from Argus Island, a U.S. Navy-U.S. Naval Oceanographic Office installation near Bermuda (Ref. 8). Figure 6 compares the wave amplitude spectrum determined from the Argus Island records and from the airborne magnetometer records. Since the Argus Island data are paper chart recordings, our method of analysis was probably not dependable to the level of the small spectral peak at 0.04 Hz (Fig. 6). This peak blows up considerably in the calculated magnetic power spectral density plot of Figure 5.

Direction of the dominant waves was determined by flying a circle at 100 feet altitude and by assuming that the aircraft was proceeding directly upwave when the highest frequency wave signal was being recorded.

Similar experiments were performed in August, 1967, again near Argus Island, with a small boat and floating accelerometer also available to measure actual wave height. Characteristics of the floating accelerometer are discussed by Brown et al. (Ref. 7). Because Argus Island is situated over a large (3,000 nT) magnetic anomaly and because the tower itself is magnetic, it was not useful to fly very close to the tower. Instead of circles, the aircraft flew a series of short (5-min.) straight line segments on each of nine different headings, all at 100 feet altitude. Power Spectral Density curves were determined for each segment, correcting for relative aircraft and apparent wave headings.

Sample magnetometer and Argus Island wave staff records are presented in Figure 7. Magnetic and wave amplitude spectra for August 28 and 30, including wave

FROM ARGUS ISLAND RECORDS:

AVERAGE WAVE HEIGHT, 8 - 10 FEET

AVERAGE WAVE PERIOD, 9 - 12 SEC

MARCH 1, 1967

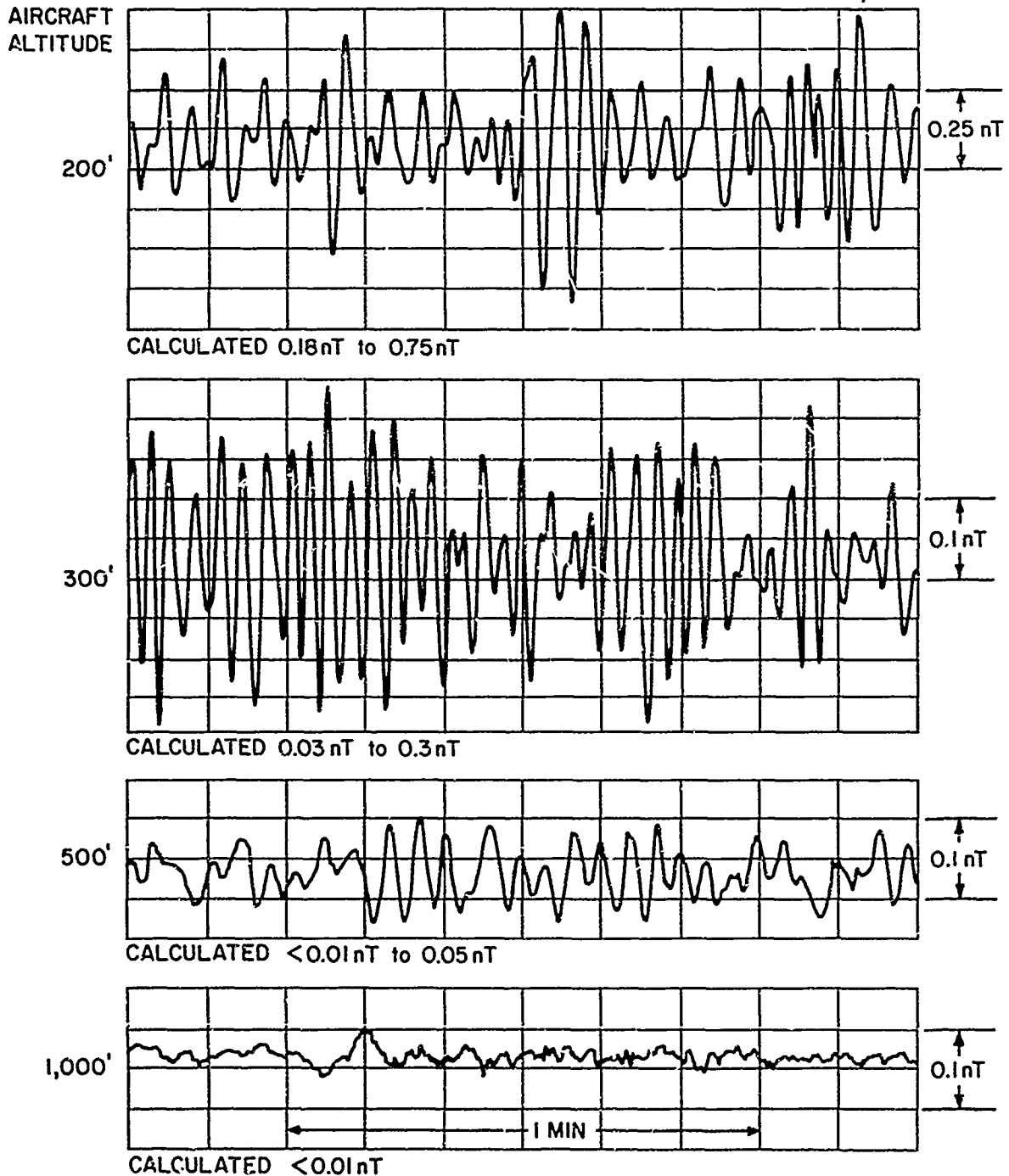


FIG. 4 : MAGNETIC FIELD OF OCEAN WAVES MEASURED AT
VARIOUS FLIGHT ALTITUDES

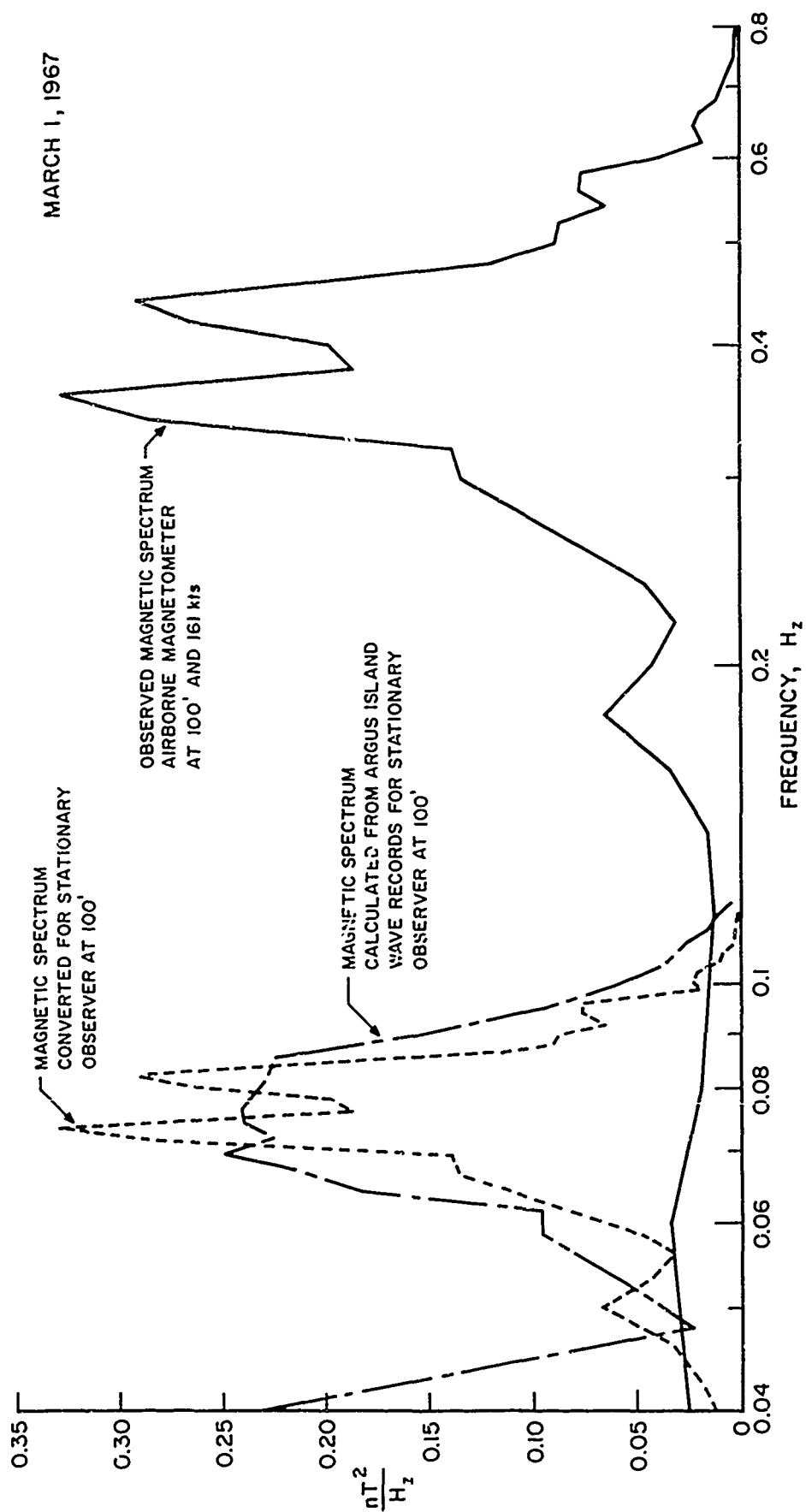


FIG. 5: COMPARISON OF AIRBORNE AND ARGUS ISLAND MAGNETIC POWER SPECTRAL DENSITIES

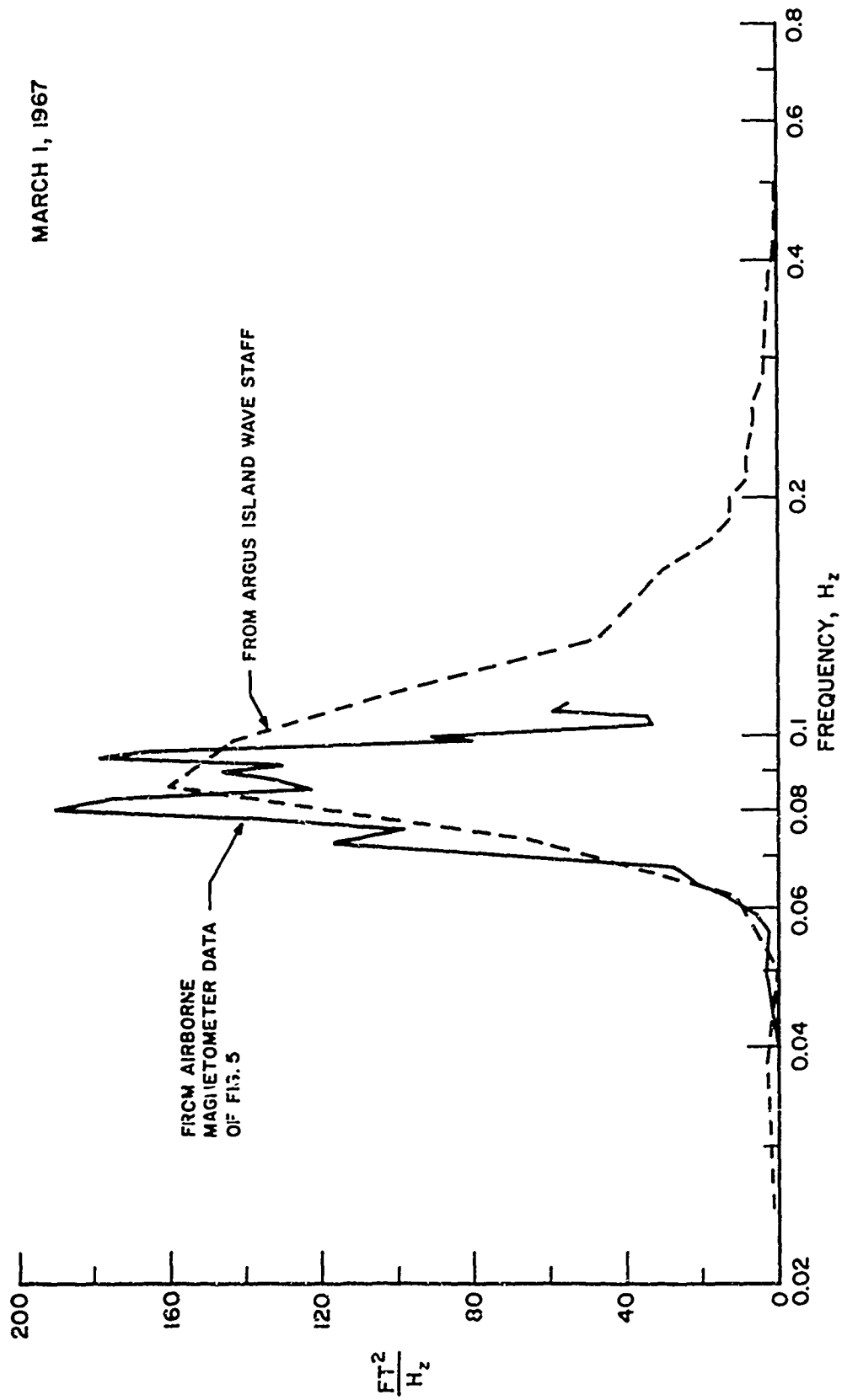
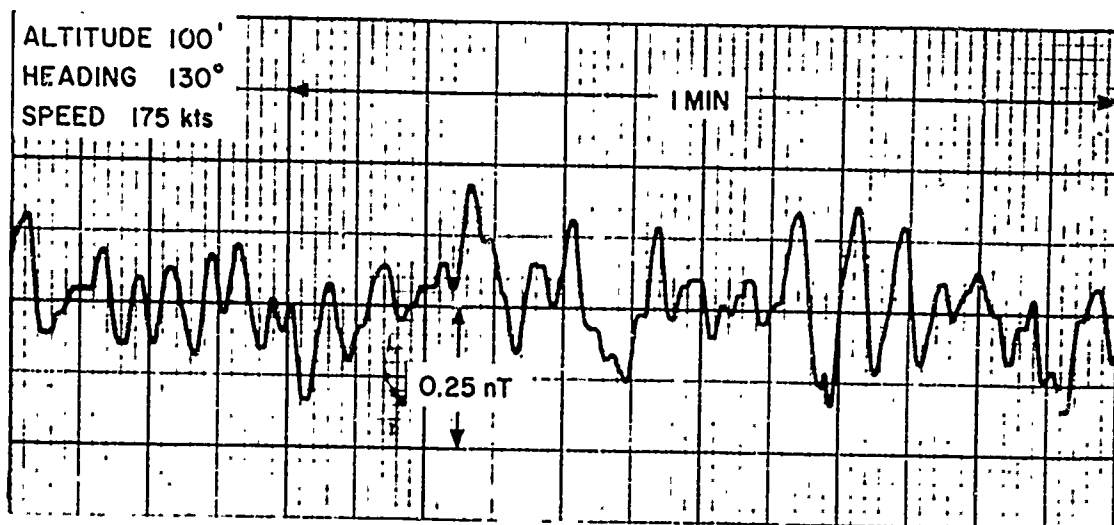
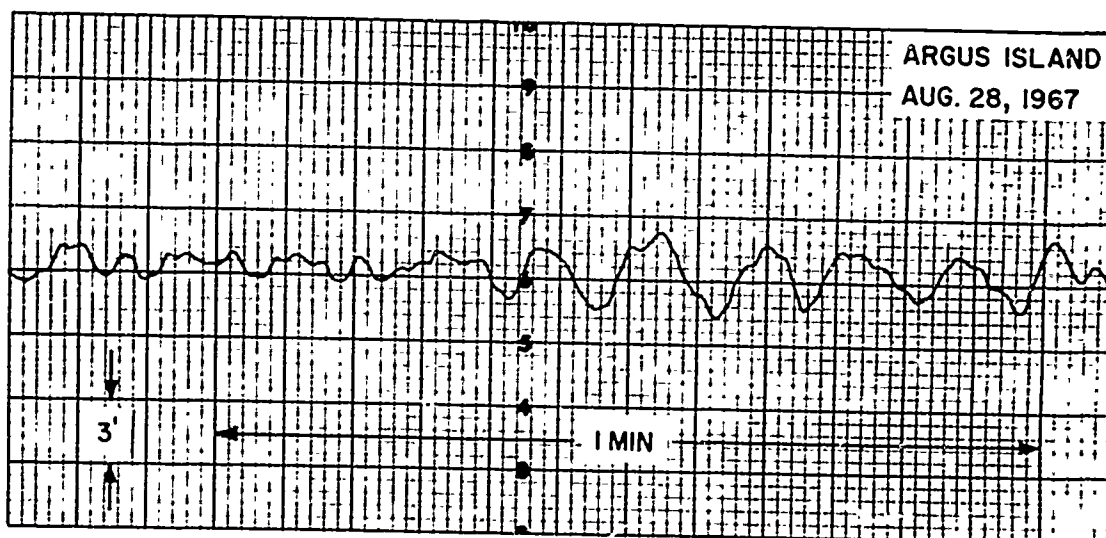


FIG. 6: WAVE HEIGHT POWER SPECTRAL DENSITIES FROM AIRBORNE AND ARGUS ISLAND DATA



AIRBORNE MAGNETOMETER RECORDING



ARGUS ISLAND WAVE STAFF RECORDING
(NOT SIMULTANEOUS WITH ABOVE MAGNETIC FIELD RECORDING)

FIG.7: SAMPLE UNPROCESSED MAGNETOMETER
AND WAVE STAFF RECORDINGS

height spectra calculated from the floating accelerometer, are shown in Figures 8 and 9. Wave amplitudes on these two days were quite small, the RMS value being on the order of 1 foot.

The magnetometer signal of August 28 exhibits a dominant peak at 0.07 Hz, which agrees in frequency if not in amplitude with peaks on the Argus Island and floating accelerometer spectra. The accelerometer power spectral density rises at the low frequency end because of inherent difficulties in the double integration of low frequency data.

The magnetometer data of August 30 exhibit a dominant peak at 0.054 Hz, which stands out above the other magnetic signals. This peak is equivalent to an RMS wave height of approximately 2.0 inches. It may be that this small wave is absent from the Argus Island spectra because of resolution difficulties in manually reading paper chart records.

5.0 METHODS OF CALCULATIONS

5.1 Power Spectral Density Analysis of Wave Noise

Suppose that we want to estimate the power spectral density of the wave height of a train of waves of frequency near f that travels in the direction θ radians east of the magnetic meridian. We have available a record of that component of the magnetic field generated by these waves parallel to the ambient earth's magnetic field. This record was obtained by flying over the waves at a height s feet at a velocity of V knots in a direction ϕ radians east of the magnetic meridian.

5.1.1 Transformation from Observed to Real Frequencies

The observed frequency f_o is related to the real frequency of the wave component by the relation

$$f_o = \left| \frac{V \cos \psi}{3.03} f^2 - f \right| \quad (7)$$

where $\psi = \phi - \theta$.

To determine f from f_o , using (7), four cases arise, namely

- | | | | |
|--------|-------------------|-----|-------------------------|
| Case 1 | $\cos \psi > 0$ | and | $V(\cos \psi) f > 3.03$ |
| Case 2 | $\cos \psi > 0$ | and | $V(\cos \psi) f < 3.03$ |
| Case 3 | $\cos \psi < 0$ | | |
| Case 4 | $V \cos \psi = 0$ | | |

Case 1 corresponds to a situation in which the aircraft has a velocity component in the direction of wave travel and is overtaking successive wave crests, while in Case 2 the aircraft, while still having a velocity component in the direction of wave

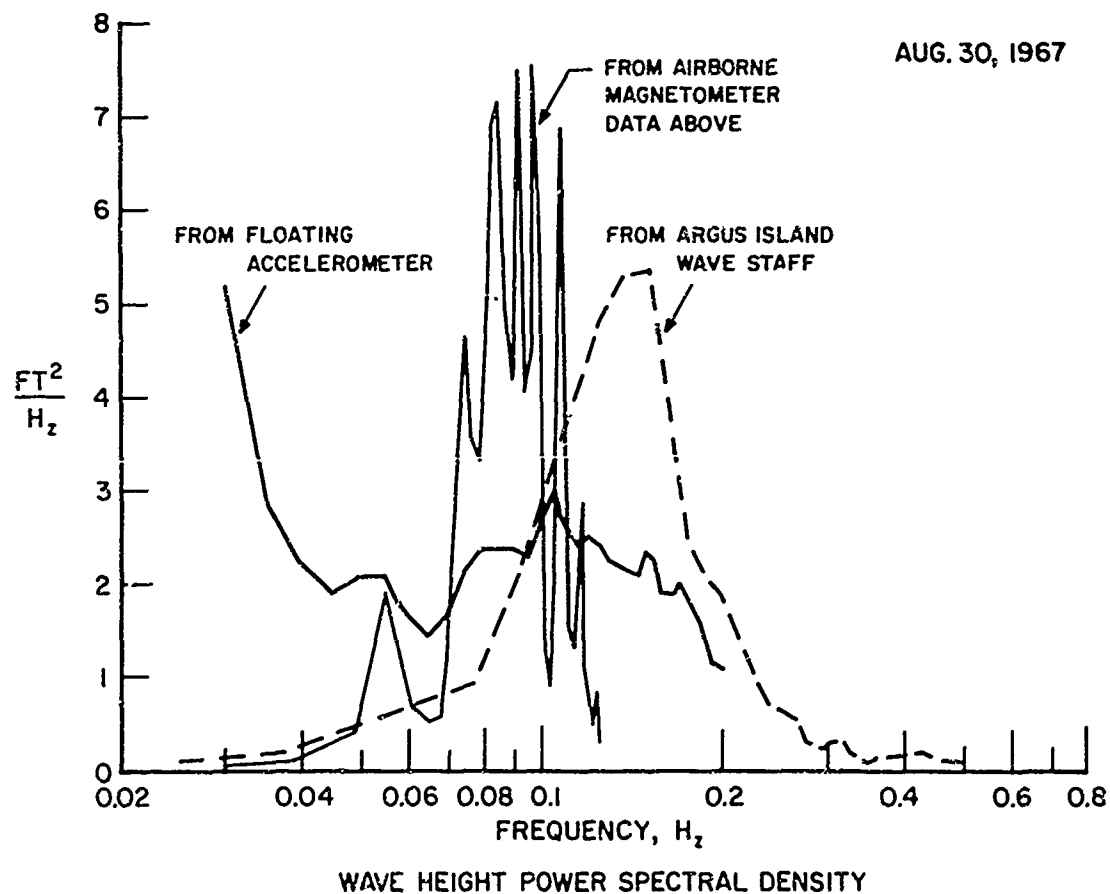
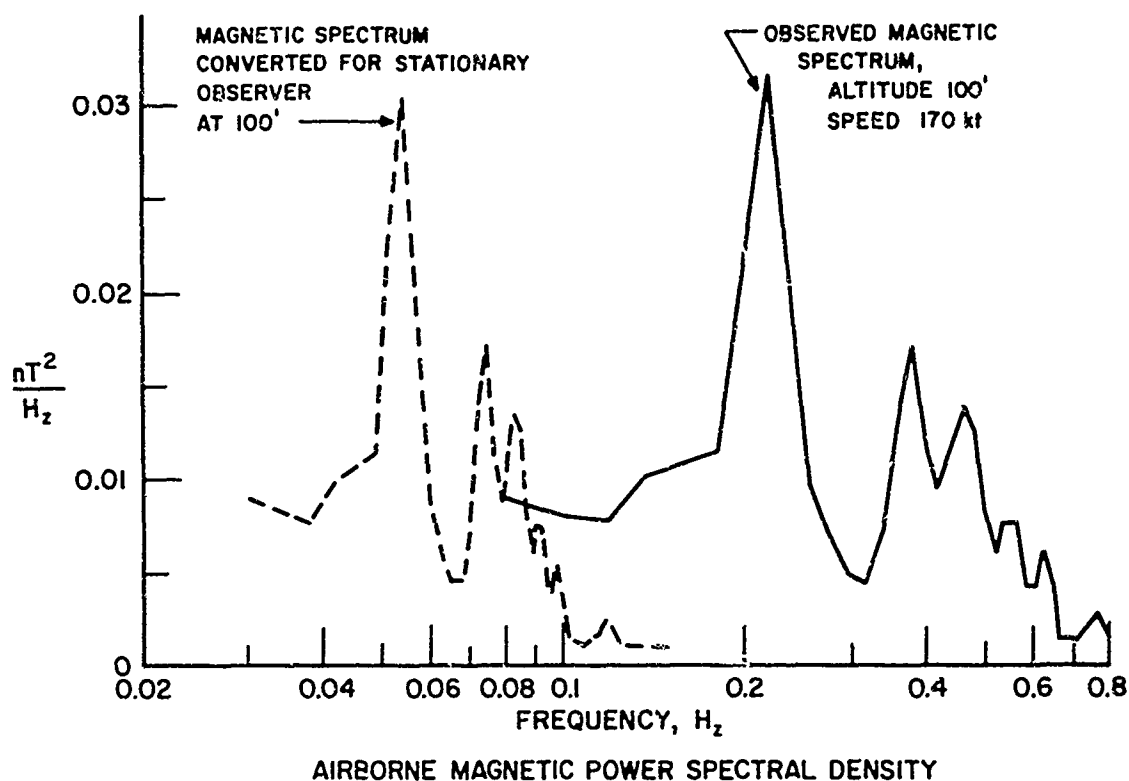


FIG.8: COMPARISON OF WAVE HEIGHT POWER SPECTRAL DENSITIES

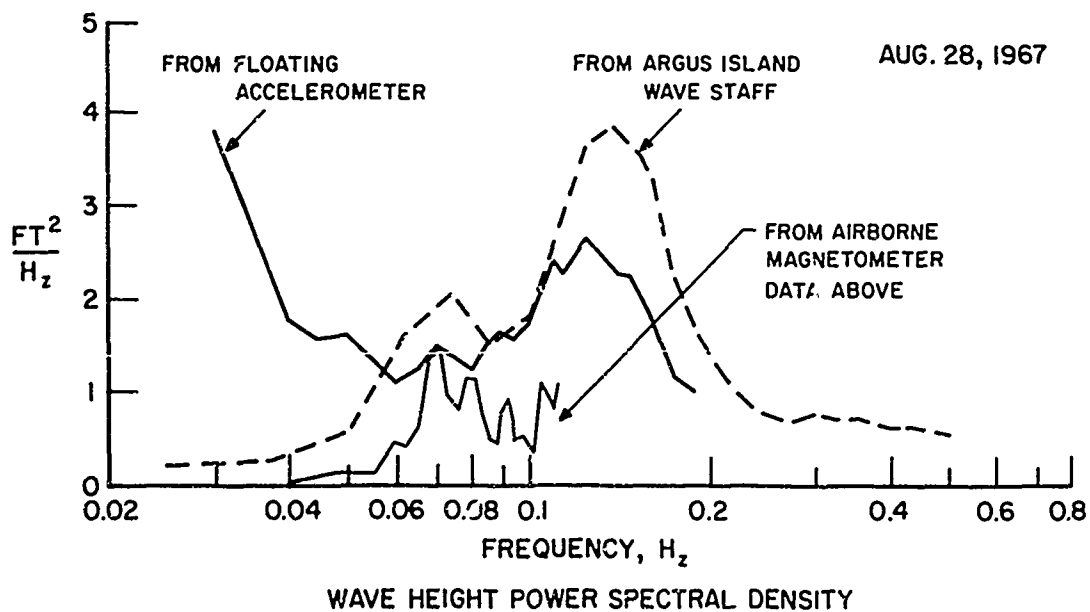
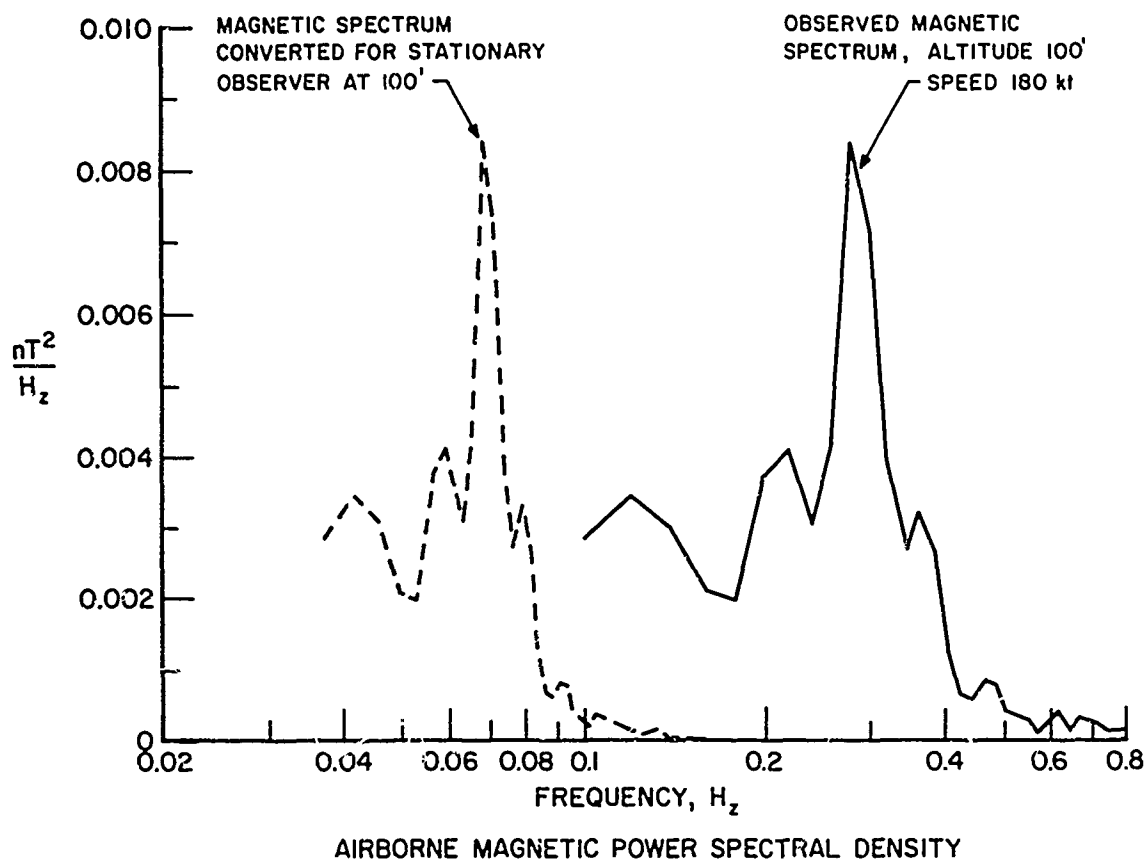


FIG.9: COMPARISON OF WAVE HEIGHT POWER SPECTRAL DENSITIES

travel, is being overtaken by successive wave crests. Case 3 corresponds to the aircraft having a velocity component in the opposite direction of wave travel, and Case 4 considers the case when the aircraft travels parallel to the wave crest. Unfortunately, owing to the nature of equation (7), observed frequencies in the range from zero to $3.03/(4V \cos \psi)$ have no one-to-one correspondence to real frequencies. In the computation of real frequencies from observed frequencies, it will therefore be assumed that Case 1 will hold whenever $\cos \psi > 0$. Hence, real frequencies between $3.03/(V \cos \psi)$ and $3.03(1 + \sqrt{2})/(2V \cos \psi) \approx 3.636/(V \cos \psi)$ (corresponding to $f_o = 3.03/(4V \cos \psi)$), will be ambiguous. The range of ambiguity can be reduced by greater aircraft speed and a smaller angle between the wave and aircraft heading.

At an aircraft speed of 180 knots and $\psi \leq 36^\circ$ every real frequency above 0.02 Hz is unique. The same speed, but with $\psi \leq 65^\circ$, results in unique real frequencies above 0.04 Hz. The real frequencies f are thus calculated from the observed frequencies from the following

$$\text{Case 1} \quad f = \frac{3.03}{2V \cos \psi} + \sqrt{\left(\frac{3.03}{2V \cos \psi}\right)^2 + f_o \frac{3.03}{V \cos \psi}} \quad (8a)$$

$$\text{Case 3} \quad f = \frac{3.03}{2V \cos \psi} + \sqrt{\left(\frac{3.03}{2V \cos \psi}\right)^2 - f_o \frac{3.03}{V \cos \psi}} \quad (8b)$$

$$\text{Case 4} \quad f = f_o \quad (8c)$$

5.1.2 Transformation from Magnetic Power Spectrum to Wave Height Power Spectrum

Suppose now that a power spectral density analysis has been made on the record of magnetic field variations as observed from the aircraft. This spectrum $S'(f_o)$ is a plot of $(nT)^2/\text{Hz}$ versus observed frequency f_o . The desired plot is the wave height spectrum $S(f)$, in ft^2/Hz versus the real frequency f . Making use of equation (1) we obtain the ratio r of wave height in feet and apparent magnetic field strength in nT at frequency f

$$r = \frac{3.34 f}{\sin^2 I + \cos^2 I \cos^2 \theta} \exp \{1.23 f^2 s\}$$

where s is the altitude of the magnetometer in feet. Thus

$$\begin{aligned} S(f) &= r^2 \frac{df_o}{df} S'(f) \\ &= \frac{1120 f^2}{[\sin^2 I + \cos^2 I \cos^2 \theta]^2} \exp \{2.46 f^2 s\} \frac{df_o}{df} S'(f_o) \end{aligned} \quad (9)$$

The term df_o/df of course depends upon which case we are considering

$$\frac{df_o}{df} = \begin{cases} - \left(1 - \frac{2f V \cos \psi}{3.03} \right) & \text{for Case 1} \\ 1 - \frac{2f V \cos \psi}{3.03} & \text{for Case 3} \\ 1 & \text{for Case 4} \end{cases}$$

5.1.3 Computer Program for Power Spectrum Calculation

A program for computing the spectral density of the observed magnetic field and conversion to the wave-height power spectrum was developed for the Scientific Data Systems SDS 920 digital computer operated by NRC's Division of Mechanical Engineering. After specifying aircraft speed, heading, and altitude, as well as an estimate of the wave heading, the computer reads low pass filtered analogue magnetic tape data that have been speeded up 16 times from real time. The correlation function of these data is computed on line, then Fourier transformed and hammed for frequencies lying in a specified range. The RMS wave height between specified frequencies is computed as well. Next, the observed frequencies are converted to real frequencies, and then the magnetic power spectral density is replotted to this frequency base. Following this, the spectrum is transformed according to equation (9) and replotted. All pertinent data connected with each plot are typed out.

A stable spectral density estimate requires as large a number of degrees of freedom as possible, which in turn requires as large a record length as possible. For a given record length one thus has to compromise between fine resolution and a large number of degrees of freedom. The resolution specified in the program is the uniform resolution of the spectrum plotted against observed frequencies. Because of the non-linear relationship between observed and real frequencies, the spectra plotted against real frequencies will have a variable resolution that becomes finer with increasing frequency.

From equation (9) it may be observed that there is an extremely large high frequency boost on the wave height spectrum, roughly proportional to $f^3 \exp(2.46 f^2 s)$. This essentially limits the usefulness of the wave height power spectrum at higher frequencies in that any small noise at these frequencies in the original spectrum will cause large values in the wave height spectrum. Low pass filtering of the recorded data before analysis is thus a definite must to prevent aliasing and the subsequent blow-up of aliased noise power in the wave height spectrum.

5.2 Determination of Wave Headings and Separation of Waves with Different Headings

If the observed waves were all travelling in the same direction and this direction were known, the spectral analysis described above would be straightforward. Unfortunately, in practice one observes waves heading in several directions, and these

directions are often hard to determine by visual observation alone, especially for low frequency, low amplitude waves, such as a 20-second period 1-foot amplitude wave. The method employed by the authors to determine the wave heading is as follows.

Field records are obtained over a given area of ocean by flying 5-minute lines in nine different directions, the directions being separated by 40 degrees from each other. A preliminary analysis of these nine records is thus made, using as a wave heading the best visual estimate obtained in the field. If this estimate were correct for a particular wave train, then the spectral peak corresponding to the frequency of this wave train would occur at the same (real) frequency for all nine records. If this peak occurs at different frequencies for the various records, then other wave headings are tried until the desired goal is achieved. If there are several wave trains present, all travelling in different directions, then, for a given wave heading (correct for one wave train), the peak for this component will occur at the same (real) frequency for all nine records, while the peaks corresponding to the other wave trains will appear at different frequencies for the different records. In this case the proper wave heading for each wave train will have to be estimated in turn in order to get a spectral density estimate near the frequencies of the particular wave train considered. Difficulties may arise in one or two of the nine spectral density plots if a wave component travelling in a direction other than the one considered at the time falls on the same (real) frequency as the wave component under analysis. In this case the area under this spectral peak would be bigger than those obtained from the other records, and it is hoped that this difficulty would be detected.

An alternate way of estimating wave headings would be to compute the spectral density for each record for assumed wave headings from 0 to 360 degrees in sufficiently narrow increments, and then check to see at which wave headings various peaks on the nine records occur at the same frequency. Trying different wave headings for one particular wave record is very fast, since the raw spectrum (nT^2/Hz versus observed frequency) is only computed once, and hence only the frequency and amplitude transformation on this spectrum will have to be computed for different wave headings. A computer program that attempts to separate different wave headings by matching "similar" spectral peaks has been written and tested, and initial results indicate that more than nine separate flight headings will be required - perhaps double this number.

5.3 Calculation of Wave Height Profile from Magnetic Field Profile

If it is known that there is only one dominant direction of wave propagation, then the wave height profile can easily be obtained from the magnetic field profile by passing the latter through a filter with a gain of $G(f_0)$.

$$G(f_0) = \frac{3.34 \left[\frac{3.03}{2V \cos \psi} + \sqrt{\left(\frac{3.03}{2V \cos \psi} \right)^2 + f_0 \frac{3.03}{|V \cos \psi|}} \right]}{\sin^2 \theta + \cos^2 \theta \cos^2 \theta} \exp \left\{ 1.23s \left(\frac{3.03}{2V \cos \psi} + \sqrt{\left(\frac{3.03}{2V \cos \psi} \right)^2 + f_0 \frac{3.03}{|V \cos \psi|}} \right)^2 \right\} \quad (10)$$

Since this gain is a function of aircraft speed, wave heading, and aircraft heading, it would be impractical to build an analogue filter with such a gain. However, by using fast Fourier transform methods one could take batches of, say, 512 samples of the magnetic field profile, Fourier transform them, perform the appropriate weighting of the Fourier coefficients, and then retransform to get the desired wave height profile. On an IBM 360/50 it would take approximately two seconds to process three minutes of flight record.

For the case of several wave trains heading in different directions the problem becomes considerably more difficult, since the previous expression for $G(f_0)$, a function of a single wave heading, is no longer applicable in this form. It would be required to obtain the true spectrum nT^2/Hz versus observed frequency by finding the wave heading for each frequency peak. From this one could express the wave heading θ as a function of observed frequency. Replacing θ by $\theta(f_0)$ in equation (10) would then give the proper gain of such a filter.

6.0 CONCLUSIONS

The data presented are suggestive of, but do not quite prove, the usefulness of an airborne magnetometer as a remote measuring device of ocean wave spectra in deep water.

Further experimentation with the airborne magnetometer and a floating wave-measuring device, probably a resistance wave staff, might allow data comparisons in the time as well as the frequency domains. Since the aircraft could fly directly over the wave staff, the data would be approximately simultaneous, avoiding the need to assume spatial statistical stationarity of the sea state.

It would be especially interesting to test the airborne magnetometer near some oceanographic facility capable of detecting waves with periods greater than 20 seconds and amplitudes much less than 1.0 inch.

This technique is relatively insensitive to aircraft vertical displacements, especially for wave periods longer than 10 seconds and, therefore, may complement the use of radar or laser profilers that require inertial altitude compensation to the same resolution as the desired wave height resolution.

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THE SHEAR COEFFICIENT: SOME EXPERIMENTAL EVIDENCE

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INTRODUCTION

Precise agreement on the theoretical value of the shear coefficient K in Timoshenko's beam theory has not yet been reached. The literature contains a great variety of values of K , among which are the values suggested by Brock¹⁾, Boley²⁾, Cowper³⁾, Goodman and Sutherland⁴⁾, Jacobsen and Ayre⁵⁾, Föppl⁶⁾, Mindlin and Deresiewicz⁷⁾, and Pickett⁸⁾. The disagreement is not as serious as the number of competing values might suggest, since most of the values lie within the rather narrow range from 0.82 to 0.90. However some anomalous values occur, such as those mentioned by Boley²⁾, and by Hardie and Parkins in their controversial paper⁹⁾. Timoshenko himself is equivocal on the matter. His original paper on Timoshenko beam theory quotes the value $K = 2/3$ for a rectangular cross section, but a later paper rejects this value in favour of $K = 8/9$.

In 1966 the writer published a new derivation of Timoshenko's beam theory³⁾, which is felt to be more rigorous and satisfactory than previous attempts. A by-product of the derivation was a new theoretical formula for the shear coefficient. Despite the theoretical appeal of the new formula, the question naturally arises whether it is supported by experimental evidence. The present article attempts to answer this question, using experimental data already available in the literature.

THE EXPERIMENTAL DATA

The vibrating uniform free-free beam is the most convenient specimen for investigating the shear coefficient. Natural frequencies can be accurately measured, the theoretically predicted natural frequencies are moderately sensitive to changes in the shear coefficient, and, most important, there is no discrepancy between the actual and theoretically assumed boundary conditions to frustrate comparison of experimental and theoretical results.

In 1959 Spinner and his co-workers at the U.S. National Bureau of Standards made a careful study of the fundamental bending frequency of steel bars¹⁰⁾. The study involved 66 different specimens of both circular and rectangular cross section and of various slenderness ratios. Reported measurements of frequency, dimensions, density, etc., were given to at least four significant figures. A study of the longitudinal vibrations of the specimens, which was carried out in addition to the study of flexural vibrations, furnished an independent check on the results, in particular on the measured value of Young's modulus. The consistency of the results and the evident carefulness of the work suggest that Spinner's measurements are highly reliable.

Spinner and his co-workers expressed their results in terms of a factor T ,

originally introduced by Goens¹¹⁾, that may be defined as

$$T = f_o^2 / f^2$$

where f is the actual natural frequency of the beam in flexural vibration and f_o is the natural frequency calculated from simple beam theory. The latter value, which is calculated on the assumption that shear and rotary inertia may be neglected, is given by¹²⁾

$$f_o^2 = m^4 E k^2 / 4\pi^2 \rho L^4$$

where E = Young's modulus
 k = radius of gyration of cross section
 ρ = density of material
 L = length of beam

and $m = 4.730$ for the fundamental frequency.

Values of T as a function of the slenderness ratio k/L are tabulated in Spinner's paper. These data will be used to check the value of the shear coefficient.

THEORETICAL DATA

Timoshenko's beam theory, which accounts for effects of shear and rotary inertia, can be used to predict the fundamental flexural frequency, and hence to obtain a theoretical value of the factor T . According to the theory, T is a function of the slenderness ratio k/L and of the quantity E/KG where K is the shear coefficient of the cross section and G is the shear modulus. Since T depends on the shear coefficient, a comparison of experimental and theoretical values of T provides an empirical check of a theoretical value of K .

The values of K recently derived by the writer³⁾ are

$$K = 6(1+\nu) / (7+6\nu)$$

for a circular cross section, and

$$K = 10(1+\nu) / (12+11\nu)$$

for a rectangular cross section, where ν is Poisson's ratio. The corresponding values

of E/KG are $(7+6\nu)/3$ and $(12+11\nu)/5$ for the circular and rectangular cross sections respectively. It is assumed that the material of the beam is isotropic, so that

$$G = E/2(1+\nu)$$

The exact solution of the Timoshenko equations for a free-free beam leads to a transcendental equation for the resonant frequencies, as given by Goens¹¹⁾ or Traill-Nash and Collar¹³⁾. For the present study, a computer program was written that solves the transcendental equation, by trial and error, to six-figure accuracy.

COMPARISON OF THEORY AND EXPERIMENT

Comparison of the theoretical and experimental values of T is shown in Figure 1. In this Figure the writer's values for the shear coefficient are used to calculate the theoretical T and Poisson's ratio is taken as 0.292, following Spinner¹⁰⁾. The largest discrepancy between the experimental and theoretical values of T is about 1.5 percent, which corresponds to a discrepancy in frequency of 0.75 percent. The upper limit of the range of slenderness ratio in Figure 1 is 0.13, which corresponds, in the case of a cylindrical rod, to a length-to-diameter ratio of about 2. It is remarkable that Timoshenko's theory can predict so accurately the resonant frequency of such stubby beams.

Although there is very good agreement between theory and experiment when the writer's shear coefficient is used, the crucial question is whether even better agreement can be obtained using some other value of K . It is apparent from Figure 1 that there is a systematic discrepancy between the theoretical and experimental values of T that increases with increasing slenderness ratio. Conceivably, the discrepancy could be reduced by altering the value of K . It is also apparent, incidentally, that the results for circular and rectangular cross sections follow distinctly separate curves.

By trial and error it was found that the discrepancy between theory and experiment can be reduced, and that the values of K that lead to the best agreement are, approximately, $K = 0.947$ for a circular cross section and $K = 0.865$ for a rectangular cross section. The comparison of theory and experiment, using these values of K , is shown in Figure 2. Clearly, there is a significant improvement over the comparison of Figure 1. The greatest discrepancy between theoretical and actual values of T is now only 0.5 percent, which corresponds to a discrepancy in frequency of 0.25 percent.

CONCLUSIONS

Timoshenko's beam theory is capable of predicting the frequency of the fundamental flexural mode of a free-free beam with an accuracy of at least 0.75 percent for slenderness ratios up to 0.13. (Here slenderness ratio means the ratio of radius of gyration of the cross section to total length of the beam.)

The best empirical values of the shear coefficient, based on the data of

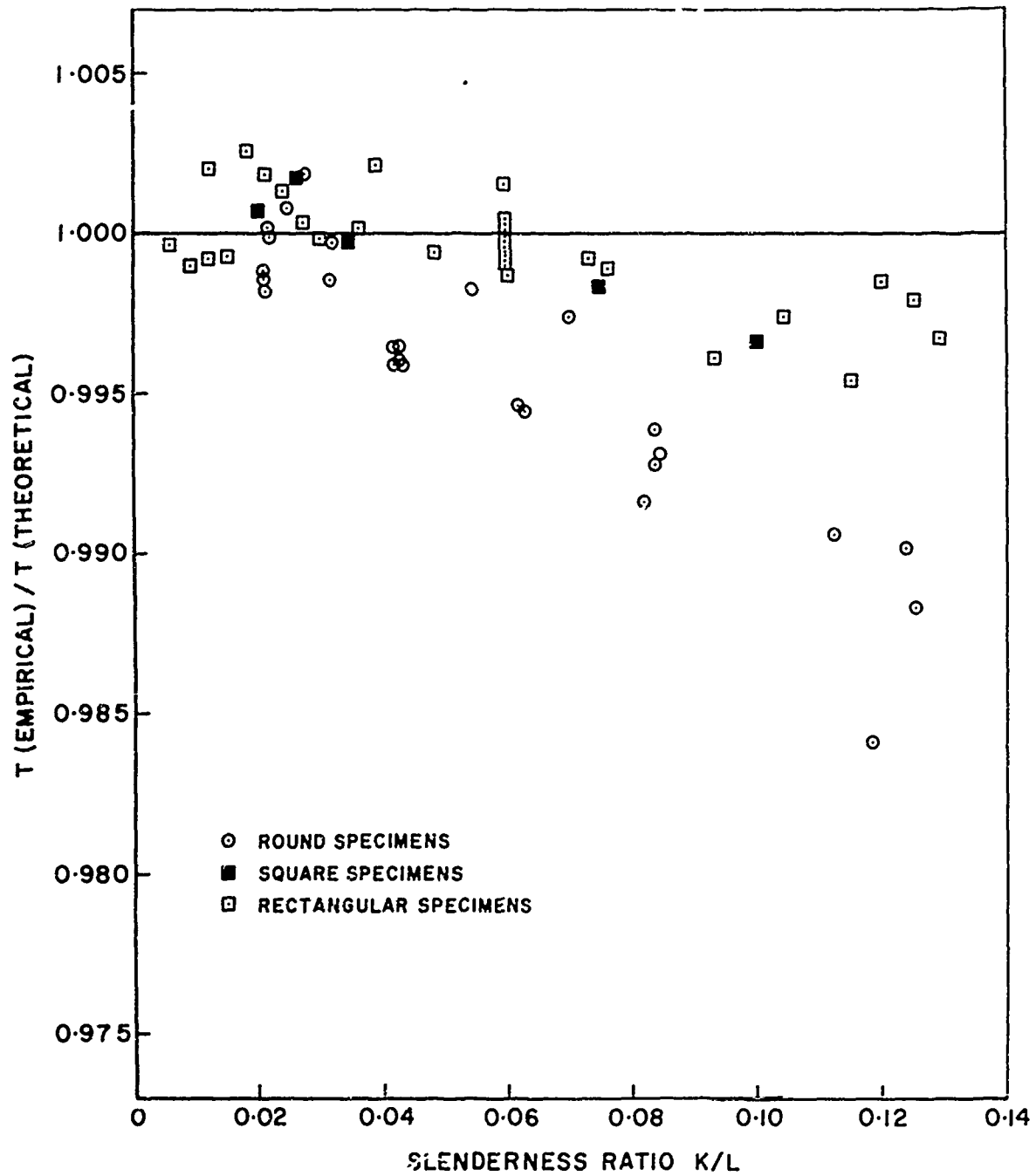


FIG.1: COMPARISON OF THEORY AND EXPERIMENT, USING COWPER'S SHEAR COEFFICIENT

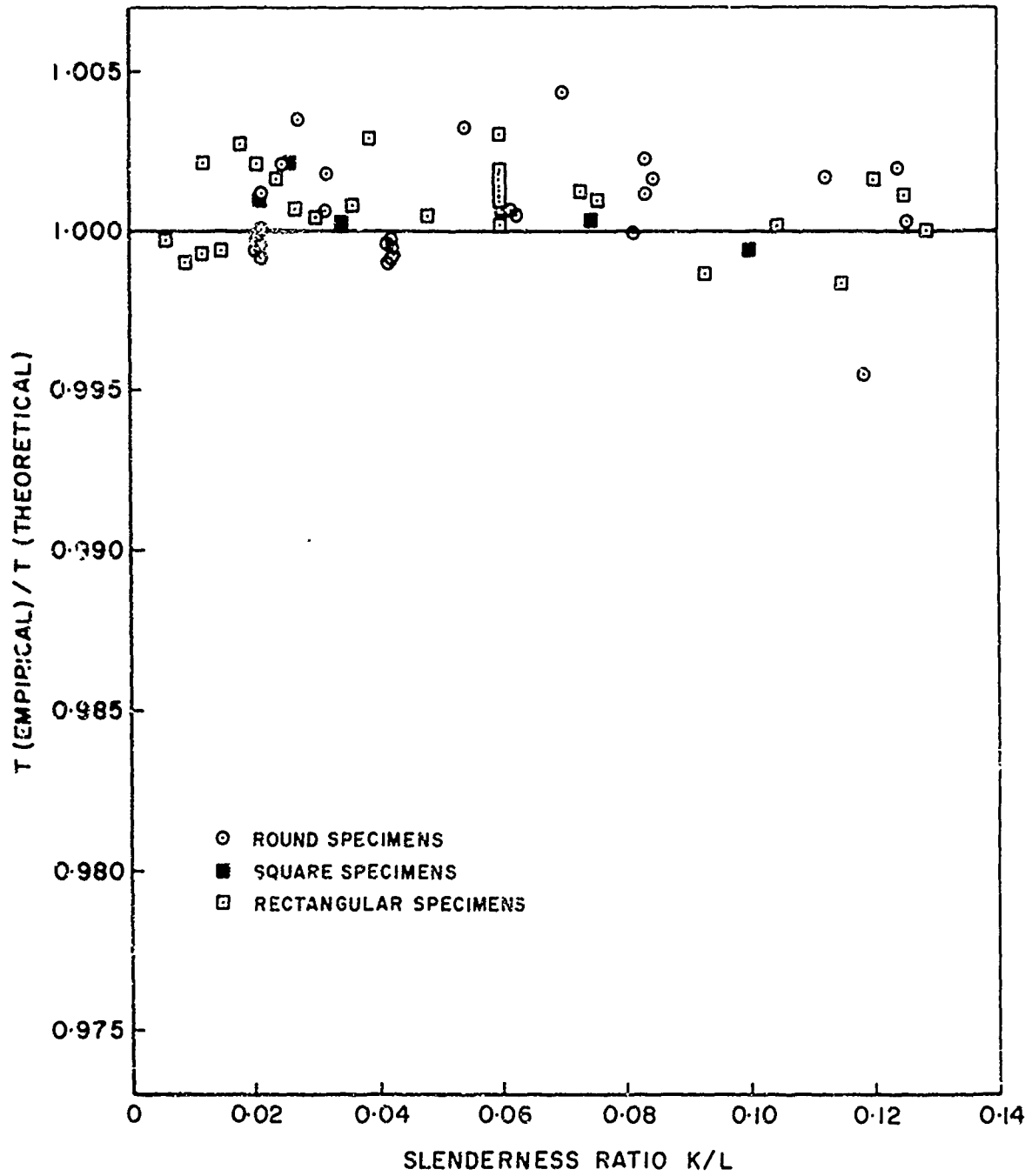


FIG.2: COMPARISON OF THEORY AND EXPERIMENT, WITH
SHEAR COEFFICIENT ADJUSTED TO GIVE BEST FIT

Spinner et al.¹⁰⁾ are $K = 0.947$ for a circular cross section and $K = 0.865$ for a rectangular cross section. These values differ from those proposed by the writer³⁾ by 7 percent and 2 percent respectively.

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THE POSSIBILITY THAT WATER DIVERSIONS AND REGULATIONS HAVE AN EFFECT ON CLIMATE

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- 1 -

At the present time some thought is being given to the feasibility of a large system study on the many effects that might result from the diversion and regulation of fresh water outflow in Canada. An aspect of this problem that is not immediately obvious but that is, at least potentially, of over-riding importance, is the possibility that large scale changes in fresh water run-off patterns could influence the climate. The purpose of this article is to present this topic in an informal way; to provide a background for thought and, possibly, to stimulate further interest and discussion.

- 2 -

The basic argument is that fresh water run-off is a primary influence on the current structures in estuaries, coastal embayments, and the off-shore ocean areas surrounding our continent. One mechanism is that of "estuarine circulation" and a general physical picture is described below.

In any sea area where there exists an excess of fresh water input over evaporation, a vertical salinity distribution will result. The exception is where total mixing occurs and the salinity is constant over the whole depth. Fresh water entering at the surface, either from land run-off or precipitation, accumulates locally over the more dense salt water until a surface pressure gradient is established that moves the fresh water away from the source region at a rate equal to its supply. This motion creates a shear relative to the lower zone that is, generally, augmented by shear stresses due to tides, surface winds, or local current distribution. The shears provide the energy for mixing. Salt water mixing upward through the shear zone is entrained by the fresh water and flows with it away from the source region. To maintain the salinity distribution, this salt must be replaced by an inward flow toward the source region below the shear zone; the vertical density distribution adjusts to provide the necessary inward pressure gradient in the lower layer. The St. Lawrence system is an outstanding example of estuarine circulation in Canada. Estimates of the total circulation involved in the St. Lawrence Gulf vary considerably, but the quantities are certainly large, many times the river flow.

Major modification to a run-off structure may be expected to result in major changes in the estuarine circulation. Since the circulation is an upward mixing whereby deep and essentially constant-temperature sea water is brought continuously into the

upper layer, it represents a moderating effect on water temperature at the surface and may contribute in a significant way to heat transfer and evaporation processes at the air sea interface. Depending on ambient air temperature (season) the circulation provides, directly, a heat source or sink to the lower atmosphere with a corresponding effect on moisture transfer.

In addition to the estuarine circulations that are driven by the fresh water run-off from rivers, it is also clear that, in cases where the surface pressure gradient may not be strong enough to move the fresh water in the upper layer relative to the lower zone to generate the shears necessary for mixing, the presence of a layer of low density water near the surface must contribute to the vertical stability of the water column. Thus, vertical convective currents, which would develop when the surface layer of a column of uniform density is cooled, are in this case inhibited. This is the situation that obtains over much of the Arctic; the fresh water run-off is an extremely important ingredient³⁾, reducing the surface salinity so that the vast amount of heat in the Atlantic layer, beneath the Arctic layer, is prevented from affecting the atmosphere above by the stability of the whole system. A similar situation may exist in the Labrador Current south of Hudson Strait, some 50 percent of which, according to Kollmeyer⁵⁾, consists of outflow from the Strait. This outflow, which maintains the characteristic low salinity of the Labrador Current, is itself a product of mixing between the Baffin Land Current and the very low salinity resident water, a product of fresh water run-off, of the Hudson Bay and Strait. The river run-off to Hudson Bay thus directly contributes to the structure and presumably also the stability of the Labrador Current. Kollmeyer's suggestion that diversion of fresh water from Hudson Bay might influence coastal temperatures in New England is, at least, a possibility.

The answer to the question, "Does fresh water run-off influence off-shore currents and circulation patterns"? is then an unequivocal "Yes, indeed profoundly so". On this point there is general agreement.

The next question might be, "Are substantial regulations and diversions of run-off likely to be made in Canada"? The reply is again, "Yes, without a doubt". Artificial retention of fresh water, for instance in the Great Lakes or in storage lakes for hydroelectric power production, is already commonplace. The scope of this type of regulation will be greatly increased by the power developments in current progress and in planning for the immediate future. Thus, the large scale modification of the natural run-off cycle of our rivers is an accepted and, increasingly, an accomplished fact. In recent years there has been a growing appreciation, particularly in the United States, of the problem of providing enough fresh water to meet the ever increasing need. The situation is already critical in the densely populated areas, and the widespread concern for the future has engendered a number of proposals for water diversion on a vast scale. The schemes are various, but have one common attribute: all of them involve southward diversion of Canadian rivers. This is of course a highly controversial and politically charged topic. It is sufficient to note that serious proposals for large scale water diversions are being made and, it may be expected, will continue to be made, perhaps more persistently, in the future.

With large scale regulation an accepted fact, and diversion schemes a far from remote possibility, it is prudent to ask about the possible effects on off-shore circulation and, by extension, on air-sea interface heat and moisture transfer to the lower atmosphere. The climatic environment may be viewed as a large system where many components interact in a complex way and it is reasonable to enquire about the effect that recognizable changes in the components may produce on the whole. An ascending scale of climatic modification by man is discernable, beginning with house construction on a scale of yards, to tree planting (acres) and irrigation (square miles). Recently cloud seeding, which is on a scale of hundreds of square miles, has given much cause for concern and study about the possible extent of its influence. The effect of cities is also well known and is receiving attention, not only on a local basis but, as in the east coast megalopolis, as a significant factor in regional climate. Because of its tremendous capacity both for storage and transport of heat energy, the sea and its motions form a major component of the climatic system. A significant change in the off-shore current structure over a large area, e.g., the 75,000 square miles of the St. Lawrence Gulf, is, at least potentially, a new order of climatic modification. Accepting that fresh water inflow is a primary influence or a control factor on coastal current regimes, then a study to evaluate the effects of water regulation and diversion on the regional climate is interesting, important and, in the Canadian context, perhaps even necessary. The most chilling aspect of a water diversion scheme is that, for all practical purposes, it is an irreversible geophysical experiment because of the large initial investment required and, more important, because of the far-reaching web of dependence that a major diversion scheme would spin. Once started, an about-face would be politically and economically impossible. In assessing the value of the proposed study, this is an important fact to keep in mind.

How then to approach the problem? It will help first to briefly restate what is involved. In general terms, fresh water outflow of a river is a control factor on the vertical salinity distribution in the off-shore ocean; it may influence profoundly the amount of mixing or exchange of waters in the surface layer either by inducing estuarine-type circulation near shore or by contributing to the vertical stability of the water column in off-shore areas; generally this vertical mixing brings deeper waters, of relatively constant temperature, to the upper layer and is therefore a moderating influence on the temperature of the surface, producing in winter a positive and, in summer, a negative heat input to the lower atmosphere. A change in the river outflow may then be expected to make some corresponding change in the heat and moisture transfer at the air-sea interface, and the summation of this effect that is of greatest interest is the extent and size of the resulting change in the climate of the land.

One is immediately led to considering particular cases by the nature of the processes involved. For instance, whether or not an estuarine circulation even exists is a function of river flow, geomorphology of the estuary, tidal volume, and prevailing wind and current structure. No two estuaries are alike and, indeed, within a given estuary the circulation pattern changes progressively seaward. The amount of heat introduced by mixing into the upper layer is a local effect dependent on vertical

temperature distribution and the depth of mixing. The extent and area of fresh water run-off influence on vertical stability of the water column off-shore depends on the initial estuarine mixing, the subsequent dispersion by prevailing winds and currents, and also the relative local precipitation patterns. Heat and moisture transfer to the air depends on prevailing winds, temperature, humidity, and atmospheric stability; similarly dependent is the effect on land climate, with the important additional complication of topography.

It is clear that each drainage system would have to be considered on an individual basis and it is instructive to ask what information would be needed, ideally, to attempt a quantitative evaluation of a proposed regulation or diversion. The processes are shown in block form in Figure 1.

Some definition of terms may be in order. "Regional" refers to very large scale processes, in the main independent of the size of perturbation anticipated by changing the fresh water outflow. "Off-shore" refers to the area where the salinity distribution may be said to depend on the fresh water outflow. "Estuary" refers to the mixing region at the mouth of the river where "estuarine circulation", as described in Section 2, is taking place. These are gray words, but precision may well be impossible and is, in any case, unnecessary at this stage. By way of illustration, "Estuary" could mean all of the St. Lawrence Gulf or, in the two extreme cases (a) of no mixing with a well-defined salt wedge and (b) of total mixing due to strong tidal action, it could mean nothing at all. "Off-shore" is primarily a function of the outflow itself, but depends also on the degree of mixing that takes place at the river mouth and on advection by ocean current regimes. Thus Hudson Bay is both Estuary and Off-shore, and possibly the Labrador Current south of Hudson Strait is Off-shore even down to the New England coast. The whole Arctic Ocean is Off-shore in this sense, involving, as it does, all the northern drainage of Russia and Canada.

The block diagram shows the Land Climate as a summation of the effects of the Regional Meteorology acting (a) directly on the Land Surface, (b) modified by Off-shore influence, and (c) modified by Estuary influence and then acting on the Land Surface. This is obviously idealised, but it appears helpful to partition the problem in this way for the present at least. In terms of the influence of fresh water outflow on heat and moisture transfer to the lower atmosphere, the Estuary and Off-shore effects are basically different and the form of the block diagram emphasises this distinction.

It is hardly necessary to state that this is a highly complicated structure. The relationship between the first cause, Regional Meteorology, and the final end product, Land Climate, is very far from being understood, as long range (and even short range) weather forecasts frequently attest. Even gross climatic averages, over long time intervals and large areas, are often bedevilled by warming, cooling, and precipitation trends extending over decades. Explanations of such phenomena provide ripe fields for conjecture and controversy.

Even in cases of relatively localised phenomena, for example the effect of near shore North Pacific sea surface temperature anomalies on the air temperatures of the British Columbia coast, the reaction of meteorological specialists is, to put it mildly, discouraging. The interaction of the many factors that affect a sea surface temperature anomaly, e.g., net surface heat exchange (comprising insolation, back and reflected radiation, evaporative heat loss, and interface heat conduction), the effect of wind and mixed layer depth, advection by surface currents, and the effects of

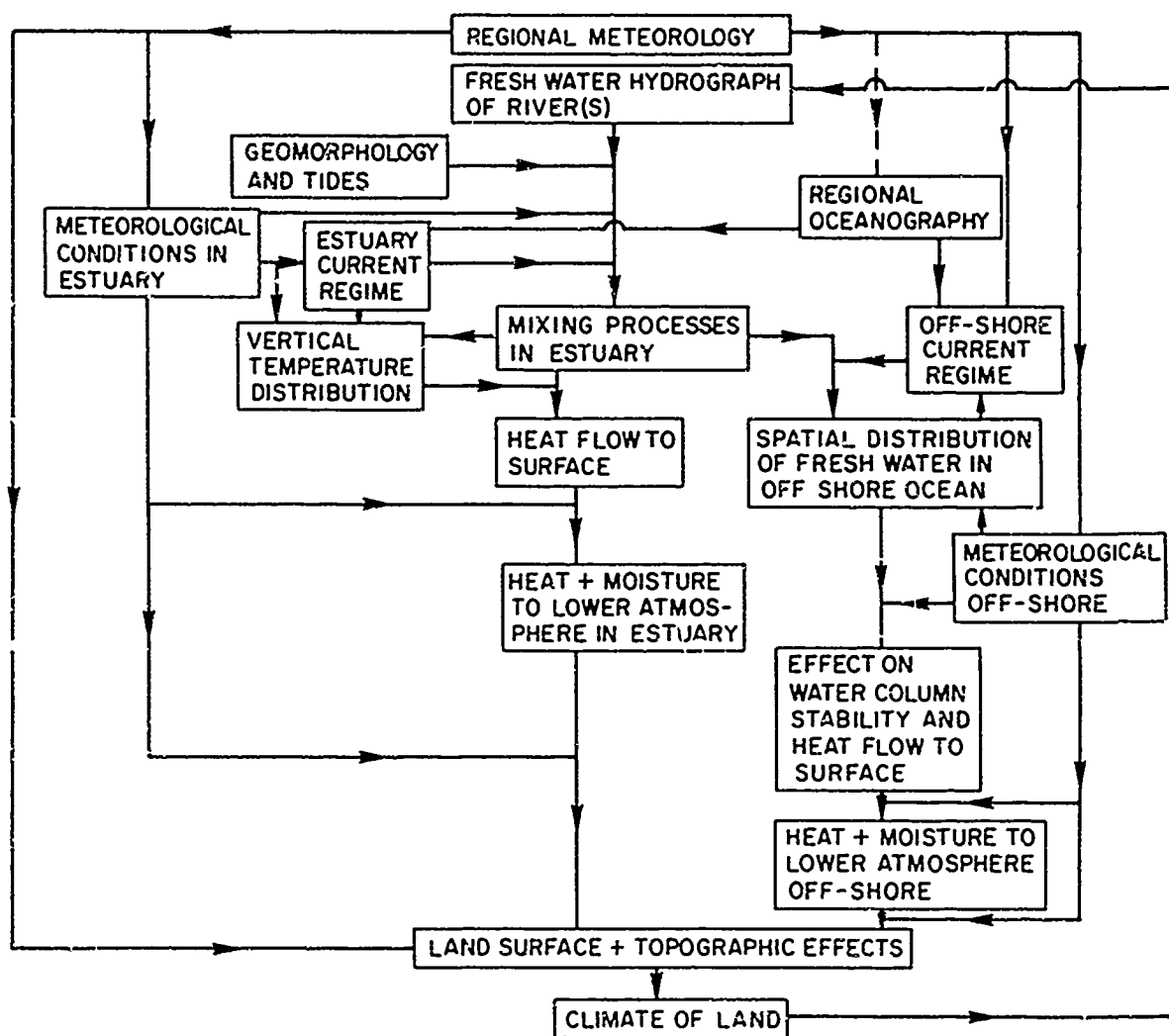


FIG.1: PROCESSES INVOLVED IN A PROPOSED REGULATION OR DIVERSION

convergence and divergence on up-welling, make separation of cause and effect a complex problem even in such a relatively clear-cut case. It is difficult not to be impressed by the general wariness, not to say hopelessness, of specialist opinion in discussing this topic. It should, however, be added that among both oceanographers and meteorologists there is a considerable enthusiasm to do something about it.

The overall relationship between regional meteorology and regional weather and climate is, then, a formidable and daunting problem; a large amount of data, accumulated from observation over the years, shows the components of climate as variables with large short-time variance and longer periodicities often without satisfactory cause. Some inroads are currently being made in the construction of multi-layer atmospheric models of the general circulation; about these it can only be said that they appear to consume vast computer capacity and are still a very, very long way indeed from the fine grain topic of interest here. Which, perhaps, brings us right to the crux of the problem - we are attempting to evaluate the effects of a perturbation, perhaps in many cases a small perturbation, on an enormous, complex, and, at this time, poorly understood system. Even granted that, in the block diagram as shown, it was possible to evaluate all of the processes and interactions so that for a given change in fresh water hydrograph the corresponding changes in heat and moisture transfer to the lower atmosphere, both in the Estuary and the Off-shore, could be determined in detail - granted all of this - the evaluation of the resultant climatic change would apparently be, in the present state of knowledge, next to impossible.

The problem, as a whole, if a serious attempt were to be made at its solution, is practically an infinite sink for scientific effort. To concentrate, for the moment, on the possible, let us ignore completely the large scale regional meteorology - land climate system and try to evaluate one specific change in fresh water outflow in terms of resultant change in heat and moisture exchange to the lower atmosphere. Presumably we would first need to determine the existing effect due to the unmodified river flow. Since the river hydrograph, the Estuary and Off-shore meteorological conditions, the vertical temperature structure, and probably also the current regimes, have an annual cycle with marked seasonal influence, it would be necessary to evaluate the river effect at least four times through the year; possibly one extra determination would be necessary during the freshet period in late spring and early summer. The minimum information required would be (i) comprehensive temperature-salinity mapping of the Estuary with a liberal sprinkling of back-up current metering, and (ii) determination of the Off-shore zone of influence (and how to do this is a large question) with temperature salinity mapping. Within the Estuary there is the additional complication of tidal influence, which necessitates averaging over the complete tide cycle, i.e., "a single determination of the geostrophic currents cannot be taken as representative of average conditions over longer than 2 hours at most; further, if the observations in a particular cross section are not complete in less than 2 hours the geostrophic current picture could be considerably distorted and hence be representative of neither an average nor an instantaneous condition" ⁴) (Forrester on the St. Lawrence near Point au Pere). What this means is that six surveys, covering the tide cycle, would be required at all sections in the Estuary. So that the task of simply mapping the behaviour of the unmodified river outflow from the source through the estuarine mixing phase to the Off-shore zone of influence shapes up as a very considerable undertaking. If one adds the complication of winter surveying, the little-known but most significant interface heat and moisture transfer characteristics that must, of course, be also determined (likely to be a combination of field survey and laboratory modelling, the latter being particularly desirable for the critical near-icing situation) - the proportions

become monumental. And thus far we have been concerned only with the zero condition.

Mathematical modelling of the Estuary and Off-shore behaviour of the fresh water outflow and of the air-sea interface transfer phenomena, probably on a basis of selected synoptic meteorological conditions representative of seasonal variation, would proceed and be refined as survey data became available. Hopefully the amount of survey data required might be reduced; in any case the two programs would obviously be co-ordinated to minimise effort. Within the present knowledge, the Estuary phase could probably be adequately modelled, but interface heat transfer phenomena are poorly known; the Off-shore phase would depend heavily on measurement. Finally, we would hope to ring the proposed changes on the mathematical model and predict the resultant effects on transfer to the lower atmosphere.

We are now on Square One of the regional climatic problem, which in the meantime, should at least be quantitatively documented, gross input-output relations established and, perhaps, even understood. On the other hand, perhaps not, and it is this possibility that gives most pause at the present stage. The big question is: could we end up chasing a relative epsilon in the larger system?

The most useful thing that can be accomplished at this stage is to avoid this possibility while maintaining due regard for the potential overall importance of the project.

As a minimum program it would be necessary to consider specific water diversions or regulations and try to determine what order of perturbation would result in the regional climatic system. Of necessity, the estimates would be crude; the object is to arrive at an upper bound on the possible effect of a realistic proposal. Given such an estimate, it may then be easier to judge whether or not it is worthwhile to pursue a more accurate determination with all that this entails. In this way some possibilities may be eliminated and the way pointed in the most promising and useful direction.

The four drainage basins in Canada, viz. Atlantic, Pacific, Arctic, and Hudson Bay should be examined with the following ends in view:

- (1) Within the bounds of realism select the most drastic scheme for regulation or diversion of fresh water that could be seriously considered.
- (2) Try to evaluate the maximum possible effect that this could have on heat and moisture transfer at the air-sea interface.
- (3) Consider this as a perturbation of the large regional climatic system and try to assess its significance. Clearly, to do this properly means solving the whole problem, but simple gross criteria of significance may, it is hoped, give useful information.

Some work on the above lines is in hand and a brief summary of findings and indications will be given. Much of what follows is conjecture and, as such, is open to argument. The purpose of this article will, however, be well served if any conclusive argument results.

The Atlantic Basin is very largely the St. Lawrence system, and here the concern is with regulation rather than diversion. Annual outflow will not be changed and, probably, the off-shore effect on water column stability will not be seriously affected. The emphasis is then on the estuarine mixing in the Gulf and the possible effect of changing the present outflow pattern through the year. From present indications this would not be a significant climatic effect. One aspect worthy of further study is the possibility of shifting the peak outflow in such a way as to delay ice formation in winter or to encourage earlier ice break-up in the spring. The St. Lawrence Gulf, in comparison with most other areas of interest, has a substantial history of oceanographic survey. Unfortunately nearly all of the data fall into Forrester's classification of "single determination ... representative of neither average nor instantaneous condition". However, it should be possible to arrive at some quantitative evaluation for this case.

With regard to the Pacific Basin, where there might be a prospect for water diversion, attention has been limited to looking at the effect of an ocean temperature anomaly on the coastal climate. This occurred in 1957-58, evidently, as reported by Tully⁶), caused by a northward drift of the warm North Pacific current, and resulted in a wide-spread positive temperature anomaly of order 2°C in the waters off the west coast of Canada that persisted for about 12 months. The order, area, and duration of this anomaly represent a natural experiment, reasonably well documented, on the kind of phenomenon with which we are concerned. Air temperature data suggest a corresponding effect and, although specialist opinion is not encouraging, this appears to be a useful structure on which to base experimental models of regional climate with direct relevance to the present problem. The effects of this anomaly should be in excess of anything that would result from river diversion. If a regional climatic model cannot be constructed to "hindcast" such an effect, then the prospects for predicting the effects of fresh water diversion from the Pacific Basin are poor indeed.

So far as the Arctic Basin is concerned only the wildest conjecture is possible. The Mackenzie River system would seem to be the obvious candidate for diversion. The stability of the Arctic Ocean is a product of (a) fresh water run-off, largely from Siberia and, (b) summer melting of ice, which reduces the upper layer salinity. The total continental drainage into the Arctic Ocean has been estimated to be 4400 km³/year (Vowinkel and Orvig⁷)). The Mackenzie outflow, 430 km³/year, is hardly significant in the overall stability picture in view of the additional contribution of ice melting. However, Coachman and Barnes²) speak of estuarine mixing in the Arctic in terms of Siberian run-off mixing and entraining a few hundred times its volume of saline water. The local Estuary phase might be examined for the Mackenzie, but confirming the guess would be a problem. It should, however, be added that large scale diversion of Russian outflow could be significant.

The Hudson Bay Basin is of particular interest for three reasons (1) Much of the speculation on water diversion involves this Basin; (2) the main circulation in Hudson Bay, an area of about 300,000 square miles is, according to Barber¹), probably driven by the large run-off; (3) if, as suggested by Kollmeyer⁵), the Labrador Current south of Hudson Strait is formed at least 50 percent by outflow from Hudson Strait, and the characteristic low salinity water of the Labrador Current emanates directly out of

the Strait, then the potential off-shore influence of fresh water run-off to Hudson Bay may well extend to the New England coast. Confirmation of (3) would certainly raise some interesting questions and there is a need for a strong oceanographic investigation of this point. In general, the prospects of determining fresh water diversion effects in Hudson Bay itself are not too good; very few data exist and the oceanography of the Bay is subject to considerable speculation (Barber¹). Surveying for about half of the year when ice is present is especially difficult. The existing climatic effect of the Bay shows most obviously in its pronounced cooling influence in summer and more widespread warming in winter, which ends in February when it is completely ice covered. The significance of this climatic effect is being evaluated.

To summarise the present position:

- (1) There is general agreement that fresh water run-off is a primary control factor on off-shore water circulations.
- (2) Major regulation, and especially diversion of fresh water run-off, by modifying heat and moisture transfer to the lower atmosphere, is potentially a new order of climatic modification.
- (3) The study of this aspect of proposed run-off changes is important and necessary.
- (4) The nature and difficulty of the problem requires that each proposal be individually studied and the effort required, mainly in survey work, to determine the zero condition for even one case, is considerable.
- (5) The study concerns the effect of a perturbation, perhaps a relatively small one, within the very large regional climatic system. The large system is poorly understood and specialist opinion is not encouraging about the prospects of determining the effects even of relatively large perturbations.
- (6) The most useful contribution that can be made at this time is to survey realistic proposals for water diversion or regulation and attempt to classify them in order of potential climatic effect. This should help to concentrate future effort in the most fruitful direction. At present it appears that the Hudson Bay Basin merits most attention.

In conclusion, an attempt has been made to air a topic that, it is believed, merits concern in this country. The subject poses many difficult questions, and, regrettably, very few have been answered. A minimum program has been suggested and some directions for useful enquiry indicated.

ACKNOWLEDGMENTS

The author wishes to acknowledge the assistance of H. Neu of Bedford Institute of Oceanography who introduced him to this topic; of Dr. W. Ford and Dr. R. Trites, also of BIO, Dr. J.P. Tully of Fisheries Research Board, F.G. Barber of the Department of Energy, Mines and Resources, and M.K. Thomas and his colleagues at DOT Meteorological Branch for valuable discussion and suggestions.

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PHOTOGRAPHIC RECORDING OF RAIL CAR IMPACTS
A STRIP CAMERA TECHNIQUE

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Division of Mechanical Engineering

INTRODUCTION

The recording of basic measurements for the study of the dynamic behaviour of railway cars and their components during impact, such as strain, displacement, velocity, and accelerations, are supplemented according to need, by high speed motion picture photography. Frame-by-frame analysis of the latter in order to reach an overall picture of the general behaviour of the cars during the impact is tedious, and a means was sought whereby a record of the impact could be made on a relatively short length of paper, and that would provide all the data relative to the motion of the cars. It was thought that this could be obtained by the use of a strip camera.

THE CAMERA

A magazine of NRC design suitable for use with photographic film or paper, 9 inches in width (high speed stabilization type photo recording paper), was available and it was decided to design the camera to take this magazine, which is shown in Figure 1. The magazine is comprised of an electrically driven transport mechanism that drives the photosensitive paper, at 6 inches per second, vertically past a horizontal slit, through which the exposure is made. The width of the slot (nominally 0.01 inch) is adjustable by the movement of one plate.

Sighting of the camera is facilitated by the use of a telescopic gun sight.

An 8-inch focal length lens is mounted in the front of the rigid camera body (Fig. 2), to the rear of which the magazine is attached, so that the photosensitive paper is exposed in the focal plane of the lens. A timing light, mounted within the camera body, exposes time reference lines onto the record when an external standard frequency of 100 cps is energized.

Figure 3 shows the camera set up for a typical test.

SPECIAL MARKING OF CARS

Initial evaluation tests were made without putting additional special markings on the cars, to determine whether the normal car markings would be adequate for the photography. Having regard to the variation in the condition of the paintwork of the cars, it was concluded that contrasting markings were desirable, e.g., by the use of strips of suitable self-adhesive tapes applied directly at known spacings along the car

and stripe-painted plates attached to components of the car. Figure 4 shows typical markings used during a recent test.

RECORD ANALYSIS

Figure 5 shows the strip camera record of an impact at approximately 6.7 mph, between a loaded hopper car (208,000 lb total weight) and a coil car weighing 63,000 lb. Time sequence is from A to C.

Reading from left to right of the Figure, we have a record of the hammer car moving towards the anvil car, which is stationary. Impact is taking place at B. The slowing up of the hammer car at B_1 , and the moving off of the anvil car at B_3 , can be seen by the change in slope of the car marker record. The interplay between the draft gears, as evidenced by the coupler movements, is clearly shown at B_2 .

With the vertical timing lines and the image of the special car markings, we have a complete time history of car position and, hence, can deduce car velocities before, during, and after the impact. At the moment we measure velocities by using an overlay of celluloid with a pair of orthogonal lines drawn on it, placed as shown in Figure 5. The time taken for the car to traverse a known distance (say, 1 foot) can be read by counting the 0.01-second lines between D and E. From the measured velocities and known masses, the momentum exchange, energy loss, and coefficient of restitution can be calculated.

CONCLUSIONS

The technique provides a permanent photographic record in condensed form of the dynamic behaviour of railway cars in impact. It requires no contact with the severe car environment.

The technique is simple, inexpensive and considerably decreases the time that the services of a motion picture photographer are required.

The record provides an excellent back-up to the conventional instrumentation so that vital information is not lost if an unserviceability of the latter develops.

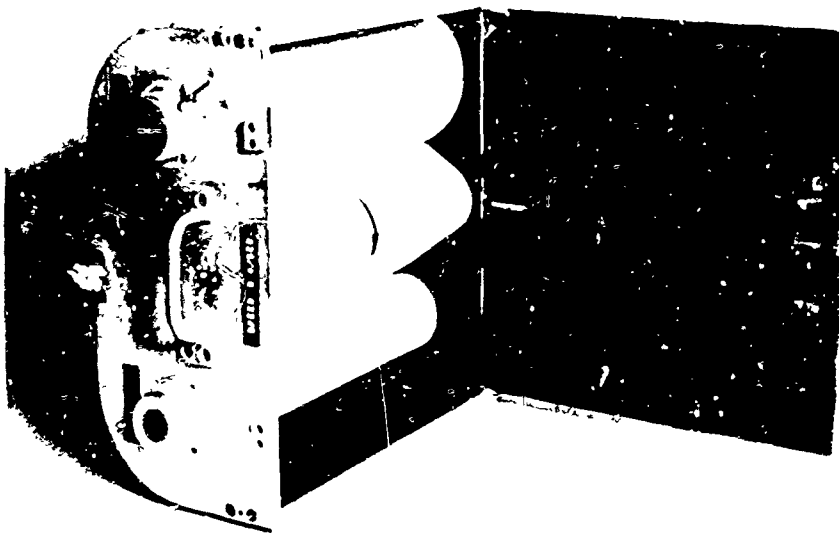


FIG.1: NRC 9 INCH RECORDER MAGAZINE OPEN
TO SHOW PAPER (OR FILM) TRANSPORT
THE SLIT IS IN THE DOOR BETWEEN THE IDLER ROLLERS

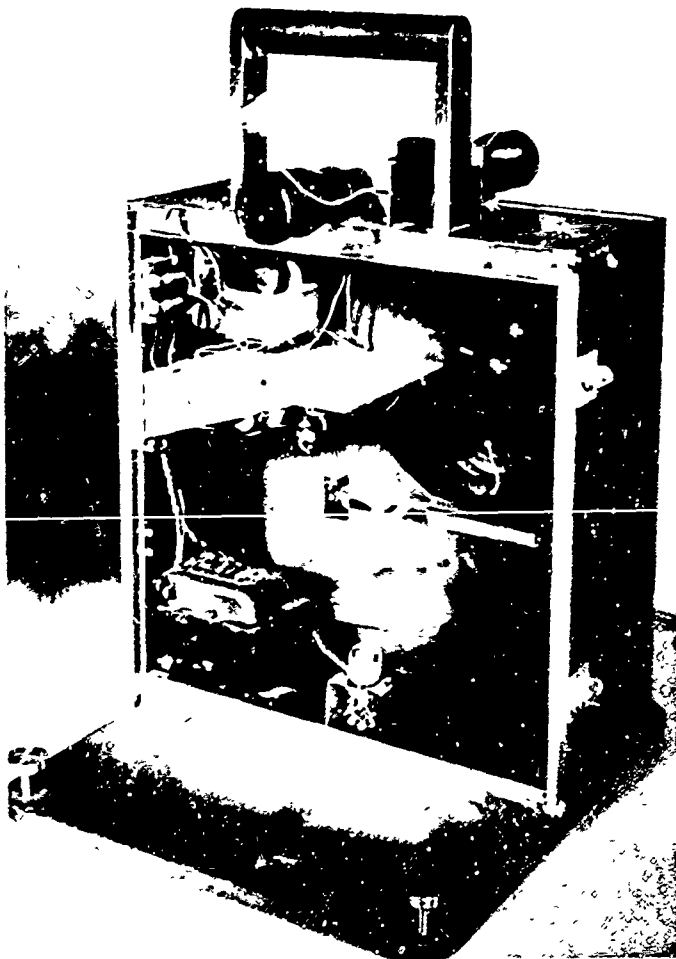


FIG.2: CAMERA FROM
THE REAR
WITH MAGAZINE
REMOVED

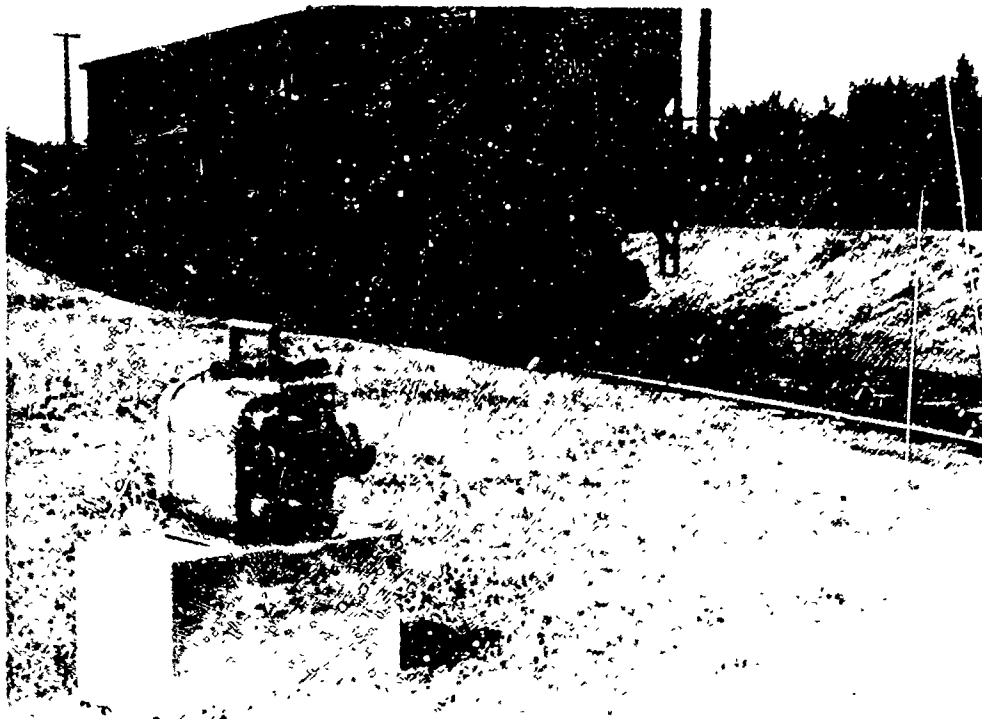
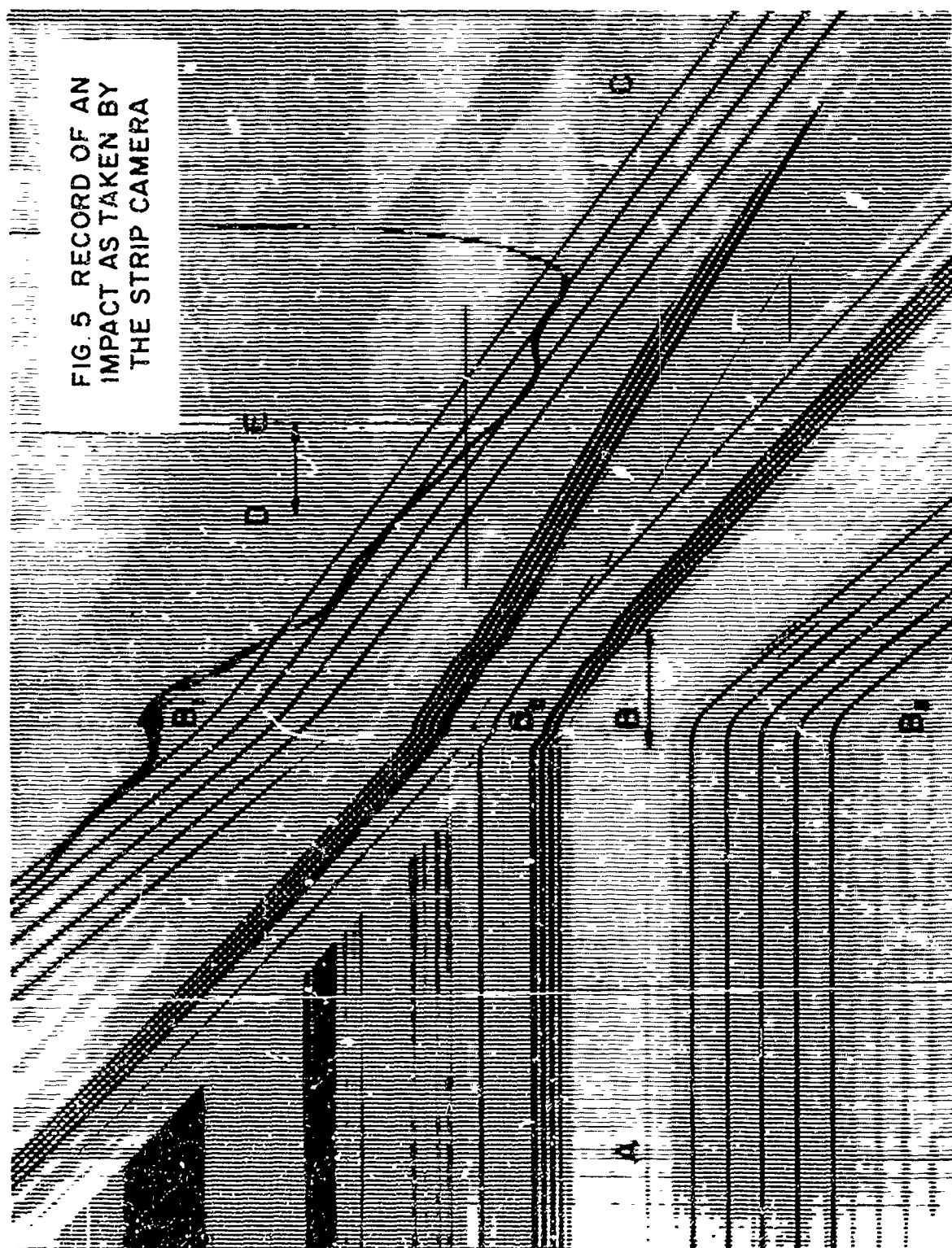
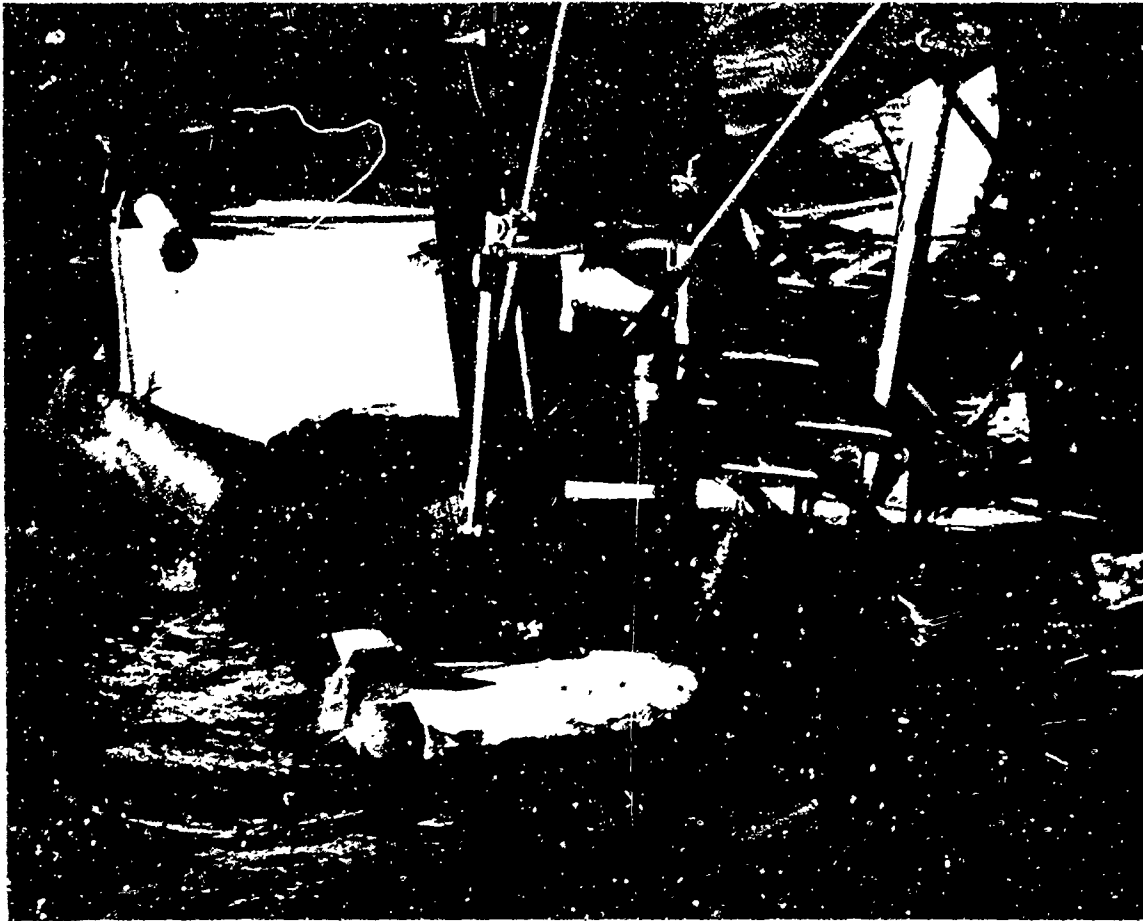


FIG.3: CAMERA IN POSITION FOR IMPACT STUDIES



FIG.4: CAR MARKINGS TO AID RECORD INTERPRETATION





STRUT-MOUNTED SUBMARINE VESSEL

This system was designed for the Department of Energy Mines and Resources in co-operation with the DME Design Section. The under-water vessel is 4-1/2 feet long and 1-1/2 feet in diameter and, in this particular installation, carries echo sounding equipment. There is a vertical pneumatic spring and piston arrangement between the vessel and its mounting to reduce the vertical hydrodynamic forces on the body (strength and cavitation) due to motions of the carrying vehicle. The complete strut and body assembly are pivoted by the piston about the vertical axis to eliminate transverse forces.

The cylinder above the strut is attached to a lifting mechanism through a safety clutch. This mechanism hydraulically lifts and lowers the body through a distance of 8 feet.

The arrangements have been mounted on the after end of a Bell Aero Systems SK5-020 hovercraft, and the first phase of echo sounding trials up to 30 knots speed are nearing completion. Excellent echo sounding results have been obtained throughout the speed range.

CURRENT PROJECTS

Much of the work in progress in the laboratories of the National Aeronautical Establishment and the Division of Mechanical Engineering includes calibrations, routine analyses and the testing of proprietary products; in addition, a substantial volume of the work is devoted to applied research or investigations carried out under contract and on behalf of private industrial companies.

None of this work is reported in the following pages.

ANALYSIS LABORATORY

AVAILABLE FACILITIES

An Electronic Associates 690 hybrid computing system is operated on an open-shop basis. The digital computer has 16K memory, card input, disc and digital plotter. The analogue computer has 120 amplifiers plus non-linear elements. A large screen (analogue) display is available for output as well as the x-y hard-copy plotters. The interface contains 32 analogue-to-digital channels, 18 digital-to-analogue channels, and logic data exchange channels. Analogue tape recorders (FM) and a manual curve follower producing punched cards are also available.

GENERAL STUDIES

Study of computing methods in optimal control.

Development of statistical analysis techniques for the analysis of analogue recorded data, including digital and hybrid implementations.

Development of digital procedures for solving a class of optimal control problems using accelerated gradient techniques.

Study of initial-value methods for the computational solution of linear and non-linear two-point boundary value problems.

Development of general digital techniques for solving multi-dimensional minimization problems via any one of user-specified algorithms.

The use of the Ricatti transformation in the numerical solution of ill-conditioned linear two-point boundary value problems.

APPLICATIONS STUDIES

In collaboration with the Flight Research Laboratory of NAE, a study is being made of magnetic fields generated by surface waves and internal waves in oceans.

In collaboration with the Flight Research Laboratory of NAE, statistical analysis techniques are being developed for the analysis of clear air turbulence records.

In collaboration with Graham F. Crate Ltd. and Trans Canada Pipe Lines, a hybrid computer simulation of a natural gas pumping station is being developed. Numerous control schemes for operating the compressors in parallel are being investigated.

In collaboration with the Low Speed Aerodynamics Laboratory of NAE, a hybrid computer simulation of an aircraft incorporating three translational degrees of freedom and engine characteristics was developed to study aircraft performance. Several military aircraft have been studied in collaboration with agencies from the USA and UK.

Hardware and software were developed to allow on-line digital plotting on an incremental plotter. The hardware included a vector generator and line code generator. Software packages included plotting in problem units with point plotting symbols and a full character set.

In collaboration with the Engine Laboratory of DME a hybrid computer simulation of a free piston gasifier is being developed. A detailed comparison between simulation results and actual engine results is now being made.

In collaboration with the Division of Applied Chemistry, hybrid techniques were developed for the analysis of analogue recorded signals generated by gas-fluidized beds. These programs are now being used on a production basis.

APPLICATIONS STUDIES BY OTHERS

The Structures Laboratory of NAE is developing EAI 640 digital programs for the analysis of digitally recorded flight data.

The Low Speed Aerodynamics Laboratory of NAE is conducting an analogue computer study of the effects of shaft torsional vibrations on the drive for the 30-ft V/STOL wind tunnel fan.

The Low Speed Aerodynamics Laboratory of NAE is developing digital computer programs for the data acquisition and reduction facilities to be installed on the 30-ft V/STOL wind tunnel.

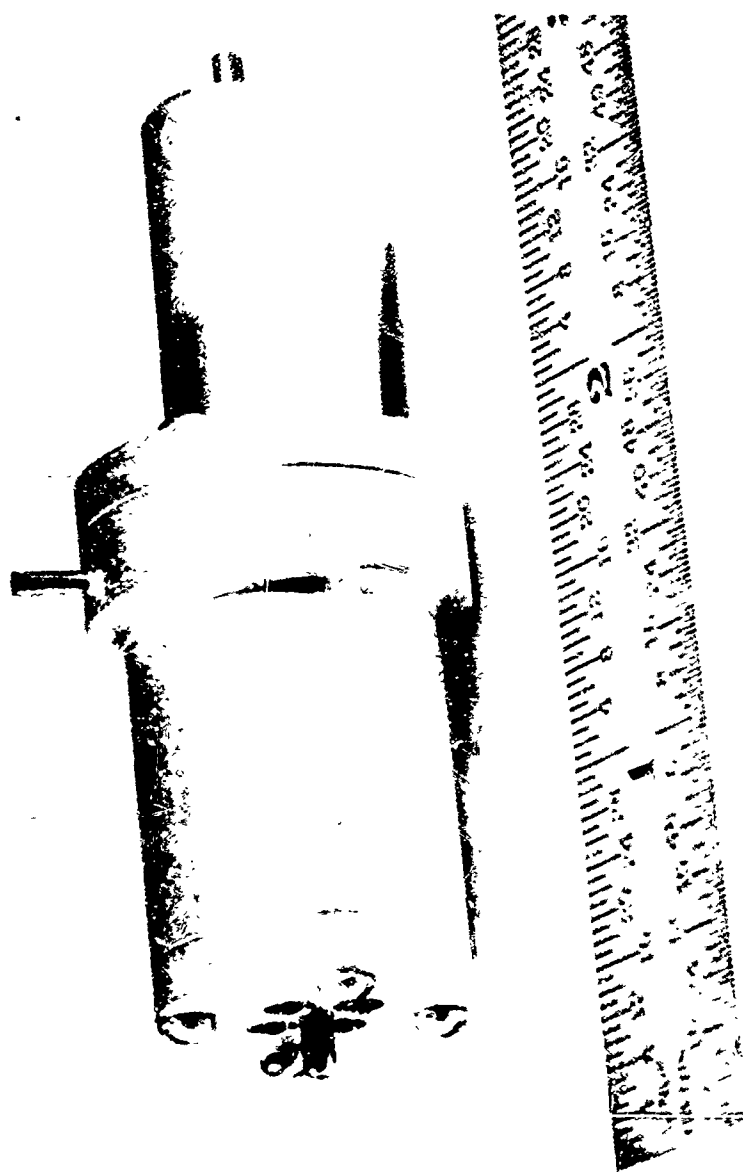
The Division of Applied Chemistry is making use of the manual curve follower to transcribe polymerization data on to punched cards for processing at the Computation Center.

CONTROL SYSTEMS LABORATORY

INDUSTRIAL CONTROL PROBLEMS

Investigation of industrial systems applications of fluidic circuits.

In collaboration with the Department of Energy, Mines and Resources, an investigation of the process dynamics and control characteristics of an electric arc furnace for processing iron ore.



ASSEMBLED EXPERIMENTAL FLUIDIC TURBULENCE AMPLIFIER
OPERATED WITH LOW PRESSURE AIR FOR JET TRANSITION
STUDIES ASSOCIATED WITH DYNAMIC SWITCHING PHENOMENON.

CONTROL SYSTEMS LABORATORY
DIVISION OF MECHANICAL ENGINEERING

Dynamic modelling of electric arc and oxygen steelmaking processes.
Investigation of the process dynamics and control characteristics of a copper converter.

LARGE SYSTEMS STUDIES

Investigation of the possible influence of fresh water outflow on climate.
Investigation of the properties and economics of large information systems.

HUMAN FACTORS ENGINEERING

A general program of research and development in the Human Factors Engineering field that includes the following:
Investigation of the control characteristics of the human operator and the basic phenomena underlying tracking performance.
Investigation of the nature of sensory interaction in human perceptual-motor performance.
Investigation of the factors involved in the presentation and processing of information, particularly in relation to simulator design.

BIOLOGICAL ENGINEERING

A general program of research and development in the biological engineering field that includes the following:
Investigation of the implementation of feedback control in living organisms.
Investigation of data transmission processes, with particular reference to nerve conduction characteristics.
Investigation of auditory methods of monitoring electrophysiological signals in general and the electroencephalograph in particular.
Development of depth probes for the study of electrical activity in the deep structures of the human brain.
Development of stereo-tactic and other apparatus for neurosurgical procedures.
Development of a phase memory filter for electroencephalograph studies.

PATTERN RECOGNITION

Investigation of the fundamentals of pattern recognition.
Development of techniques for the identification of biological cell populations, fingerprints etc.

BIRD DISPERSAL BY MICROWAVE RADIATION

Investigation of the effect of low-intensity microwave radiation on the behaviour of birds on the ground and in the air, to determine the practicability of using microwave radiation for dispersing birds on airfields and from the flight path of an aircraft.

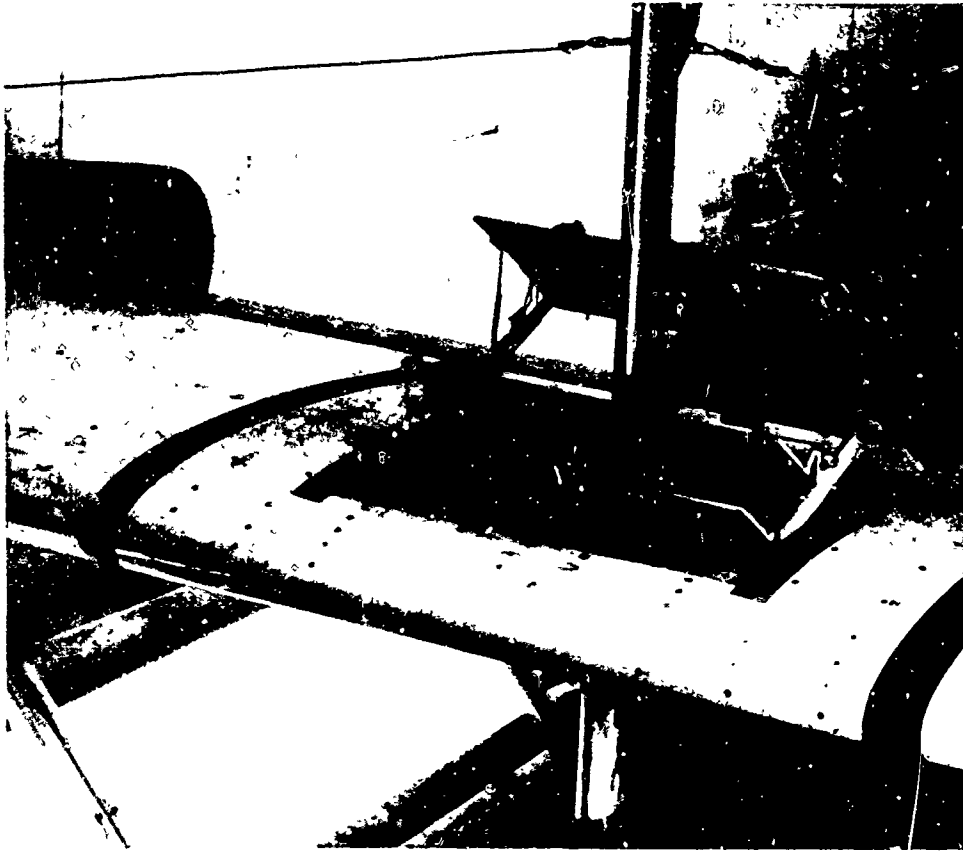
ENGINE LABORATORY

FREE PISTON ENGINES

Study of the free piston engine and its applications, including various methods of power take-off. Mathematical study of the dynamic and thermodynamic processes in the engine, using computer simulation techniques, with a view to elucidating starting and control phenomena. Experimental assessment of the operation and performance of the free piston engine in the laboratory. Study of the injection system most suitable for the peculiar requirements of the free piston engine, with possible application to all direct injection engines.

DUCTED FANS

Aerodynamic performance study of highly loaded ducted fans, with particular reference to inlet distortion phenomena as encountered typically by VTOL aircraft. The study comprises both analytical and experimental parts. Experimentally assessed performance of a fan-in-wing model in a wind tunnel over a range of inflow ratios and wing angle-of-attack settings.



12-INCH GEAR-DRIVEN FAN-IN-WING MOUNTED IN THE
10-FOOT x 20-FOOT PROPULSION TUNNEL FOR TESTS
ON A TRIPLE VANE CASCADE AS A FAN INFLOW AID.

FAN-IN-WING VTOL SYSTEM

ENGINE LABORATORY
DIVISION OF MECHANICAL ENGINEERING

ENGINE CYCLE STUDIES

Performance calculations of gas turbine powerplant systems, with particular reference to VTOL aircraft. Extension of earlier rigorous design-point analysis to cover off-design point equilibrium operation, using analytically derived differential coefficients to generate rapidly converging trial parameters.

V/STOL NOISE STUDIES

Study of the mechanism of the generation and suppression of noise produced by ducted fans for VTOL aircraft. Identification of the noise sources and relating the strength of the sources to the physical parameters of the system.

CENTRIFUGAL COMPRESSORS

Design and performance investigation of centrifugal compressors, including study of flow phenomena in oversize model impellers. Detailed study of stability and distribution of flow in a single passage in support of previous investigations of flow in a complete impeller.

AXIAL COMPRESSORS

Preliminary analytical and experimental studies of small axial compressors.

LOCOMOTIVE DIESEL ENGINE PROBLEMS

In co-operation with the Canadian National Railway and the Canadian Pacific Railway, an investigation of locomotive diesel engine problems, including those arising from the use of Canadian crude oils as fuel. Studies of wear processes in the engine employing a specially developed, new method of spectrographic sampling of cylinder oil. Investigation of several new types of lubricating oil, different kinds of cylinder liners etc. with respect to engine wear.

FOAMED-CLAY MATERIALS

Investigation of novel light-weight foamed-clay building materials, with respect to chemical composition and physical properties.

FLIGHT RESEARCH LABORATORY

DESIGN AND DEVELOPMENT TESTING OF A CRASH POSITION INDICATOR FOR HELICOPTERS

Experiments on models, supplemented by theoretical analyses, are being conducted for the purpose of evolving an improved crash position indicator for helicopters.

AIRBORNE REMOTE SENSING OF MAGNETIC PHENOMENA

Experimental and theoretical studies relating to the use of magnetic airborne detection equipment. Equipment under development is installed on a North Star aircraft, which is used as a flying laboratory and for preliminary surveys requested by various Government Departments and other agencies.

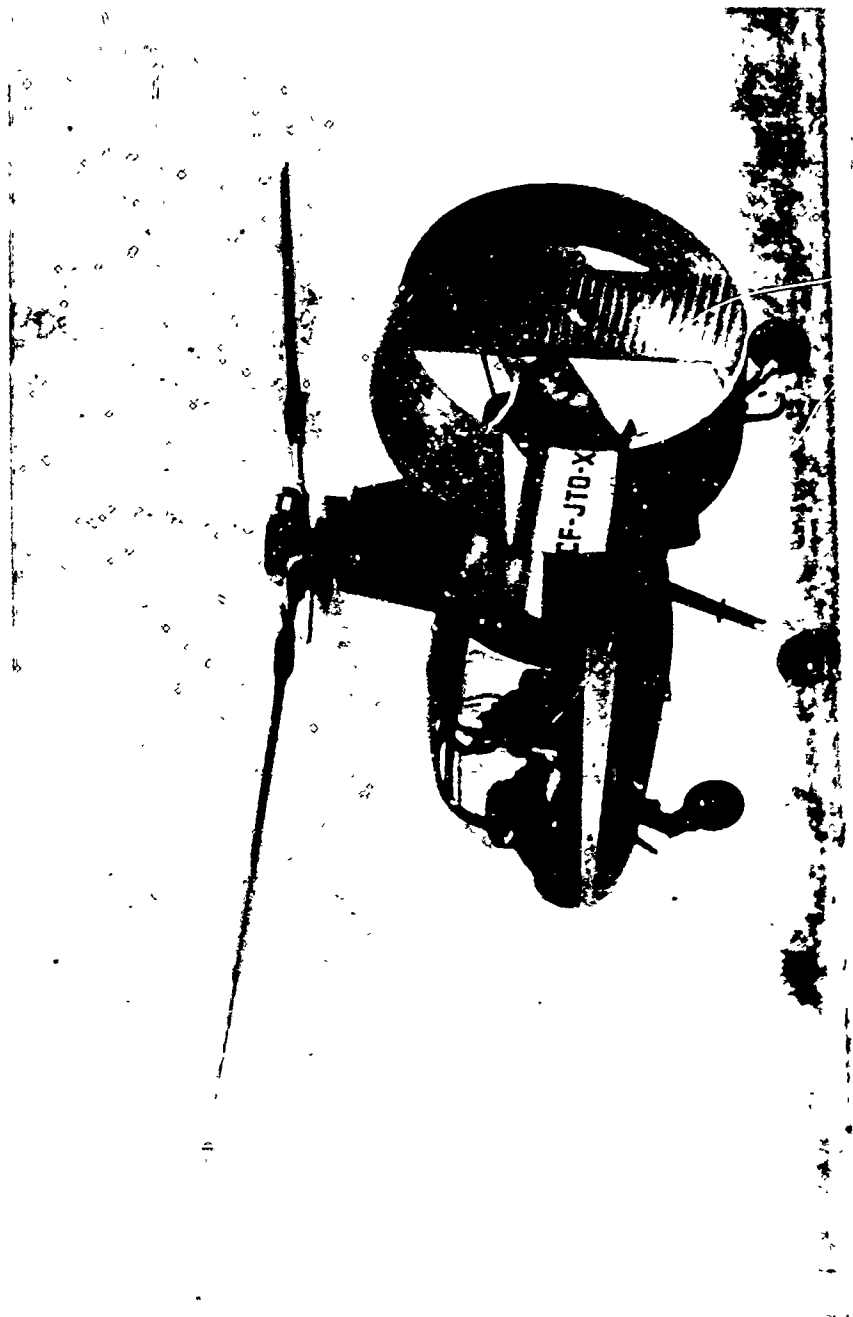
A Beech Queen Air aircraft is also being equipped and operated for the Department of Energy, Mines and Resources as a prototype for future general aeromagnetic surveys.

AIRBORNE REMOTE SENSING USING INFRA-RED TECHNIQUES

The same North Star aircraft is being used in investigating the potentialities of airborne infra-red techniques in hydrological surveying, soil, and permafrost studies and other possible applications.

INVESTIGATION OF FLYING QUALITIES AND CONTROL SYSTEM REQUIREMENTS APPLICABLE TO V/STOL AIRCRAFT

Airborne simulation techniques, using helicopters equipped to provide variable stability and control properties, are being employed to explore the effects of the numerous parameters involved and to produce data that are directly applicable for design purposes. Specific investigations are also being conducted for aircraft manufacturing firms and other agencies. Whenever possible direct comparisons are made between results obtained using the helicopter equipped as an airborne simulator and results obtained on actual VTOL and STOL aircraft.



IN ADDITION TO TAKE-OFF AND LANDING MEASUREMENTS THE
FLIGHT RESEARCH LABORATORY HAS INVESTIGATED THE POSSIBLE
OCCURRENCE OF PITCH/ROLL OSCILLATIONS ON THIS CONFIGURATION.

PROTOTYPE, AVIAN 2/180 GYROPLANE COMPLETING FLARE
PRIOR TO ZERO-RUN LANDING

FLIGHT RESEARCH LABORATORY
NATIONAL AERONAUTICAL ESTABLISHMENT



CANADAIR CL - 215 FIRE-BOMBER MAKING
1200-GALLON SPLIT DROP IN RECENT GROUND
DISTRIBUTION MEASUREMENT PROGRAM.

FLIGHT RESEARCH LABORATORY
NATIONAL AERONAUTICAL ESTABLISHMENT

INVESTIGATIONS OF AIR CUSHION VEHICLES

Occasional studies relating to possible applications of air cushion vehicles in agriculture and in Northern transportation.

INVESTIGATIONS RELATING TO FOREST FIRE CONTROL BY AERIAL METHODS

Studies of various factors determining the effectiveness of aerial fire suppression methods, including theoretical and experimental work on the behaviour of liquids released into an airstream, operational analyses, and the investigation of aircraft design requirements. Data on aircraft behaviour and on liquid drop patterns are being obtained from flight experiments with a number of typical fire-bombing aircraft.

INVESTIGATION OF ATMOSPHERIC TURBULENCE

A T-33 aircraft, equipped to measure wind gust velocities, air temperature, wind speed, and other parameters of interest in turbulence research, is being used for several investigations. These include measurements at very low altitude, in clear air above the tropopause, in the neighbourhood of mountain wave activity, and near storms. Records are obtained on magnetic tape to facilitate data analysis. Clear air turbulence detection methods are also being investigated. The aircraft also participates in co-operative experiments with other Canadian and foreign research agencies.

GYROPLANE FLIGHT CHARACTERISTICS

Flight investigations of the dynamic characteristics and some performance features of a prototype jump-take-off autogyro are being carried out in response to requests for assistance during certification.

AIRCRAFT OPERATIONS

Various studies relating to aircraft operations are made from time to time. These may involve such matters as the provision of technical assistance during accident investigations, the analysis of particular aspects of aircraft behaviour in operations, or the preparation of recommendations on flight recorder requirements and specifications.

FUELS AND LUBRICANTS LABORATORY

HYDROGEN-OXYGEN ENGINES

Experiments with small-scale equipment to obtain data on ignition at low pressures.

Theoretical studies aimed at producing the best design features for hydrogen-oxygen engines in multi-stage vehicles.

Investigation of heat transfer in a 500-lb thrust rocket combustion chamber using a water-cooled chamber burning hydrogen and oxygen.

Experiments on cryogenic tankage.

FUNDAMENTAL STUDIES OF FRICTION, LUBRICATION AND WEAR PROCESSES

Analysis of friction and wear processes including the seizure of lubricated surfaces and the action of soft metal solid film lubricants.

Analysis of the mechanism of adhesion between non-conforming metallic surfaces.

PRACTICAL STUDIES ON LUBRICATION, FRICTION AND WEAR

Assessment of wear in shotgun barrels with shot manufactured from different materials.

A co-operative program for the assessment of instrument oils and lubricant surface coatings in the bearings of miniature rotating electrical components.

COMBUSTION RESEARCH

Experiments on fuel spray evaporation.

STORAGE PROBLEMS

Evaluation of drum coating effectiveness and fuel deterioration in the long term storage of hydrocarbon fuels in coated steel drums.

EXTENSION AND DEVELOPMENT OF LABORATORY EVALUATION

- Investigation of laboratory engine test procedures for evaluation of oxidation, dispersancy, and thermal stability characteristics of engine oils.
- Development of laboratory full-scale axle procedures for the determination of the anti-score performance of hypoid gear oils.
- Evaluation of methods for determining the electrical conductivity of aviation fuels.

PERFORMANCE ASPECTS OF FUELS, OILS, GREASES, AND BRAKE FLUID

- Co-operative investigation covering used oil analysis and inspection of engines from Ottawa Transportation Commission buses to establish realistic oil and filter change periods.
- Engine and bench test studies on the deterioration of engine crankcase oils with particular emphasis on the role played by oxides of nitrogen.
- Investigation of the significance of Water Separation Index, Modified, in relation to filter/separator performance.
- Continuing studies of chain saw lubricants in the chain saw tests, and standard laboratory evaluation methods including correlation with field performance and wood cutting trials.
- Development of a specification for high viscosity index hydraulic oils for marine use.
- Examination and evaluation of some re-refined oils.
- Investigation of laboratory methods for predicting flow properties of engine and gear oils under low temperature operating conditions.
- Investigation of laboratory methods for predicting low temperature flow properties of diesel and heating fuels and assessment of their suitability.
- Evaluation of methods for determining undissolved water content of aviation turbine fuels.
- The effect of automotive hydraulic fluid low temperature properties on the functioning of a modified stroking test.
- Low temperature performance of hydraulic oils in pump systems.
- Investigation of lubricating oil performance in water-cooled 2-stroke engines.
- Development of a laboratory method for evaluating the shear stability of multigrade motor oils.

MISCELLANEOUS STUDIES

- The preparation and cataloging of infra-red spectra of compounds related to fuels, lubricants, and associated products.
- The application of Atomic Absorption spectroscopy to the determination of metals in petroleum products.
- Investigation of the stability of highly compressed fuel gases.

GAS DYNAMICS LABORATORY

V/STOL PROPULSION SYSTEMS

- A general study of VTOL propulsion system methods with particular reference to requirements of economy and safety.
- Investigation of a VTOL engine arrangement involving a shrouded fan driven by a partial admission turbine.
- Experimental investigation of a pod-mounted VTOL fan for studies including the effects of flow distortion in cross-flow and shroud thrust effects.
- Examination of wing intakes for VTOL propulsion systems with the objects of wing boundary layer laminarization and bird exclusion.
- Examination of the pressure field associated with the efflux from a wing of a downward-directed air jet of variable cross-section and inclination.

INDUSTRIAL GAS TURBINES

- Investigation of a gas turbine type suitable for geared turbine locomotives.

INTERNATIONAL AERODYNAMICS OF DUCTS

- An experimental study of the internal aerodynamics of ducts, bends, and diffuser with particular reference to the effect of axial variation in cross-sectional shape.

HEAT TRANSFER STUDIES

The study of heat transfer within a vertical sealed tube (thermo-syphon) in which working fluid is boiled in the lower section and condensed in the upper section.

HYDROSTATIC GAS BEARINGS

Studies of hydrostatic gas bearings to develop reliable methods of predicting bearing performance for a range of conditions and configurations, and to evolve suitable techniques for the satisfactory application of this type of bearing in situations where the special properties of gas bearings recommend their use.

ARC PRODUCED PLASMA STUDIES

A general investigation of the properties and flow behaviour of thermally ionized gases produced by arc heating on a continuous basis, together with the development of suitable diagnostic techniques for the study of such high temperature gases.

SHOCK PRODUCED PLASMA STUDIES

A general theoretical and experimental investigation of the production of high temperature plasma by means of shock waves generated by electromagnetic or gasdynamic means, and the development of diagnostic techniques suitable for a variety of shock geometries and the study of physical properties of such plasmas.

A theoretical and experimental study of strong converging and diverging shock waves, produced by chemical (explosive) and other means, and the development of experimental means to study the resulting transient plasma.

INDUSTRIAL PROCESS INSTRUMENTATION

There is an appreciable effort on a continuing basis directed towards industrial assistance. This work is of an extremely varied nature and, in general, requires the special facilities and capabilities available in the laboratory. The following examples of work during the past year are typical: altitude performance of small gas turbine engine; hydraulic pump tests; centrifugal compressor tests for pipeline service; design and test of heaters for laying continuous rails on Canadian railways; assistance in air bearing design for industrial applications; instrumentation for copper and iron smelter applications; design and experimental verification of pressure loss data for large air ducts in smelters; industrial and aero turbine development.

HIGH SPEED AERODYNAMICS LABORATORY

WIND TUNNEL TESTS ON AN AEROELASTICALLY-SCALED ROCKET MODEL

Static stability wind tunnel tests have now been completed on a flexible model of a meteorological rocket at Mach numbers from 0.6 to 4.23. After the failure of the first model in September, a second model was built with a stiffened nylon nose section and redesigned stabilizing fins, and testing was resumed in mid-October. This second model was also destroyed, late in the test program, when the forward half broke off during a "fins-off" run at $M_\infty = 4.23$. Data had been collected for the "fins-on" configuration up to $M_\infty = 3.0$ and it was deemed that this, plus the "fins-off" data up to the time of failure, was sufficient to meet the test requirement.

TESTS ON THE MOBY SERIES OF UNDERWATER TOWED BODIES

A $\frac{1}{4}$ -scale model of the Naval Research Establishment's Moby underwater towed body has been tested in the 5-ft wind tunnel to determine the panel loads on one wing. The normal force, pitching, and rolling moments on the starboard wing were measured, using a 3-component wing root balance specially designed and manufactured at NAE that gave very satisfactory results. The wind tunnel test program (approx. 35 runs), has been completed.

MORTAR SHELL TESTS

Using the spinning model facility described in Report DME/NAE 1988(3), two mortar shell models have been tested (for CARDE) up to spin rates of 180 rev/sec, giving surface speed ratios of about 0.6. Static stability measurements, with particular emphasis on the spin-induced Magnus forces, were carried out for Mach numbers from 0.3 to 1.1.

TWO-DIMENSIONAL AUGMENTOR WING STUDIES IN THE 5-FOOT WIND TUNNEL

The augmentor wing is a system, related to the well-known blow flap and jet flap techniques, to allow the operation of aircraft at the high lift coefficients required for short take-off and landing. An air ejector, utilizing air available from

a jet engine, is incorporated into the wing structure and is controlled and directed by the variable passage formed by elements of the flap system. A two-dimensional model has been prepared for testing in the transonic working section of the NAE 5-ft wind tunnel. Tests will determine the two-dimensional aerofoil characteristics of the augmentor wing at landing and cruising speeds with full simulation of Reynolds number.

INVESTIGATION OF DYNAMIC FLOW CHARACTERISTICS IN THE TRANSONIC TEST SECTION OF THE 5-FOOT WIND TUNNEL

Fluctuating flow angles and pitot pressures were measured in the transonic test section at Mach numbers of 0.6 and 0.88. The measurements, which showed no dominant frequency in the fluctuating flow angles, had maximum amplitudes of up to ± 1 deg. The rms value of the fluctuating flow angles was about 0.3 deg. The maximum test section pitot pressure fluctuations were $\pm 2.8\%$ at a dominant frequency of about 210 cps.

As a complement to these measurements, flutter tests were also performed with a sting-mounted flutter model. The wind tunnel was then operated in its variable stagnation pressure mode. The flutter tests were deemed to be successful.

This investigation was a joint undertaking between NAE and the Lockheed California Company, who supplied all the models. These same models have been used in other wind tunnels for similar investigations.

FLOW SEPARATION ON BODIES OF REVOLUTION

The flow over a 54-in long 6:1 ellipsoid of revolution has been investigated experimentally in the NAE 5-ft wind tunnel at subsonic Mach numbers of 0.3 and 0.7 at a Reynolds number per foot of about 10^6 . Flow visualization tests were first conducted and preliminary analysis indicates that at low incidence (below 15 deg) only a very small region of symmetrical bubble type separation with reverse flow exists over the leeward side of the aft end. At higher incidence, three-dimensional flow separation of the leeward boundary layer occurred first, at some indeterminate upstream station. At some further downstream station another separation line is observed at a smaller circumferential angle. The flow is entirely symmetrical, even with separation present, up to at least 25 deg incidence.

Flow visualization tests were followed by surface pressure measurements as well as Preston tube measurements of surface shear stress. The results are being analyzed. The above tests were performed for the benefit of Laval University.

CONTROL OF A TURBULENT BOUNDARY LAYER IN A THREE-DIMENSIONAL SHOCK WAVE/BOUNDARY-LAYER INTERACTION

The 5-in \times 5-in blowdown wind tunnel is being used to investigate the three-dimensional interaction between a glancing, oblique shock wave and a turbulent boundary-layer flow along a flat wall. In a second phase, the boundary-layer flow in the three-dimensional interaction region will be re-energized by tangential air blowing.

THEORETICAL RESEARCH ON THREE-DIMENSIONAL COMPRESSIBLE LAMINAR BOUNDARY LAYERS

The effects of discrete blowing and suction on three-dimensional boundary layers are being examined. A numerical method for the solution of this problem with small cross-flow is being developed.

HYPERSONIC THREE-DIMENSIONAL BOUNDARY LAYER

Experiments on two slender cones with half-cone angles at 15 deg and 5 deg have been completed. Measurements of pressure distribution, heat transfer and surface flow direction are being compared with theoretical results for laminar boundary layers.

HYPERSONIC INTERNAL FLOW STUDIES

The fundamental aspects of internal flows are being investigated. In the theoretical phase of this project the inviscid flow fields on intakes with arbitrary body shape at zero incidence are computed, using an imploding shock analogy and a multi-strip shock layer theory. Viscous interaction is also included. A mixed method using finite differences and the method of characteristics will be developed for the internal flow at angle of incidence. Laminar three-dimensional boundary-layer growth will also be investigated.

Surface pressure and heat transfer measurements, shock shapes, and static and pitot pressure traverses in the shock layer for a 5-deg and 10-deg leading edge conical intake at $M = 8.33$ and 10.4 are being performed in the hypersonic gun tunnel.

SCHLIEREN SYSTEM

All the basic elements are now assembled. Optical trials on the test stand and completion of mechanical components and control electronics are proceeding.

Loss of resolution in the system when porous acrylic sheet is in the optical path, due, apparently, to internal residual stresses caused by drilling, is being assessed along with other optical aspects.

Small cracks encountered in one of the precision optical glass windows has resulted in a delay while the surface is reground and polished.

HYDRAULICS LABORATORY

ICE FORMATION AND MOVEMENT

Field observations to determine the heat budget and mechanism of freeze-up on the St. Lawrence River from Kingston to Three Rivers.

WAVE RECORDER DEVELOPMENT

Development of a staff gauge wave recorder, either to be mounted to a fixed mast in shallow water or floating in deep water. Evaluation of other types of wave recorders: accelerometers, pressure transducers, etc.

ST. LAWRENCE SHIP CHANNEL

Under the sponsorship of the Department of Transport, a study of navigation, water levels, tide and ice problems.

DYNAMIC MODEL OF LAKE ONTARIO

A fundamental study of the wind and thermally induced circulations in Lake Ontario.

WAVE INTERACTION STUDY

An experimental investigation to study the development of a wave cascade resulting from the dynamic instability of a uniform progressive wave train of finite amplitude.

WAVE DIRECTION STUDY

Field investigation to study the direction of propagation of wave energy in a confused sea as a function of wind direction.

COBOURG SUBMERGED BREAKWATER

Model study to estimate the forces acting on a submerged barrier.

LOCK STUDY

General study of navigation locks and locking systems, with particular emphasis on winter operation.

SEDIMENT PROBLEMS

To define and analyze sediment problems in navigable waters.

INSTRUMENTS LABORATORY

FREIGHT CAR STUDIES AND CAR DYNAMICS

Observation and measurement of temperature and dimensional changes of a 400-ft length of welded rail using a variety of arrangements for rail heating and also rail cooling.

Measurements of the forces in various forms of 'tie-downs' of particular military vehicles on railway flat cars.

Experiment with a new form of newsprint roll restraint during a series of car impacts.

Continuation of construction of an arrangement for the static longitudinal compression of freight cars ('squeore-frame').

Continuation of investigation into the build-up of forces behind strings of standard and hydraulically cushioned cars in freight trains.

IMPACT RECORDER

Field tests showing the practicability of simultaneous outputs of displacement, velocity, and acceleration. Construction of prototype model commenced.

BOARD THICKNESS GAUGE

Continuation of solid state circuit development for gauge for continuous measurement of board thickness during log sawing.

NON-CONTACTING PROXIMITY GAUGE

Development of a capacitive non-contacting precise multi-purpose distance measuring device for immediate application to model wave amplitude measurements.

ST. LAWRENCE RIVER MODEL

Continued development of computer programs for tide generation and the logging of water level and flow velocity data; also of components to interface the model control and data logging system, with the computer.

AIRPORT NOISE PROBLEM

Consideration of the existing noise problem at a large Canadian airport and possible developments of the problem associated with projected airport extensions.

LOGGING INDUSTRY

Measurements of the vibration characteristics of a range of chain saws of a particular make, for study of the operator acceptability of these designs.

MECHANICAL AIDS TO SURGERY

Assembly and laboratory development of a hydraulic pump unit proposed as the power unit for a powered lower limb orthosis.

Laboratory evaluation of the mechanical characteristics, including fatigue, of an experimental form of prosthetic venous valve, 5 mm in diameter.

Clinical use of the vascular suturing instruments in transplant surgery at a local hospital. Consideration of re-design of the Mark 12 instrument (6-12 mm) to reduce its weight and size.

LOW SPEED AERODYNAMICS LABORATORY

AERONAUTICAL WIND TUNNEL TESTS FOR OUTSIDE ORGANIZATIONS

In the 6-ft x 9-ft horizontal wind tunnel, tests were carried out on four models for DeHavilland Aircraft of Canada, Limited.

NON-AERONAUTICAL WIND TUNNEL AND WATER TUNNEL TESTS

In the 7-ft working section of the 15-ft vertical wind tunnel, an elastically suspended model was used to determine the aerodynamic stability of a proposed bridge for the Northumberland Straits crossing. A study of the instability of bundled power conductors was also initiated in this tunnel. The 10-in x 13-in water tunnel was used for a flow visualization study of wind flow over a topographical model as part of a DOT aircraft accident investigation.

THE NRC 30-FOOT V/STOL WIND TUNNEL

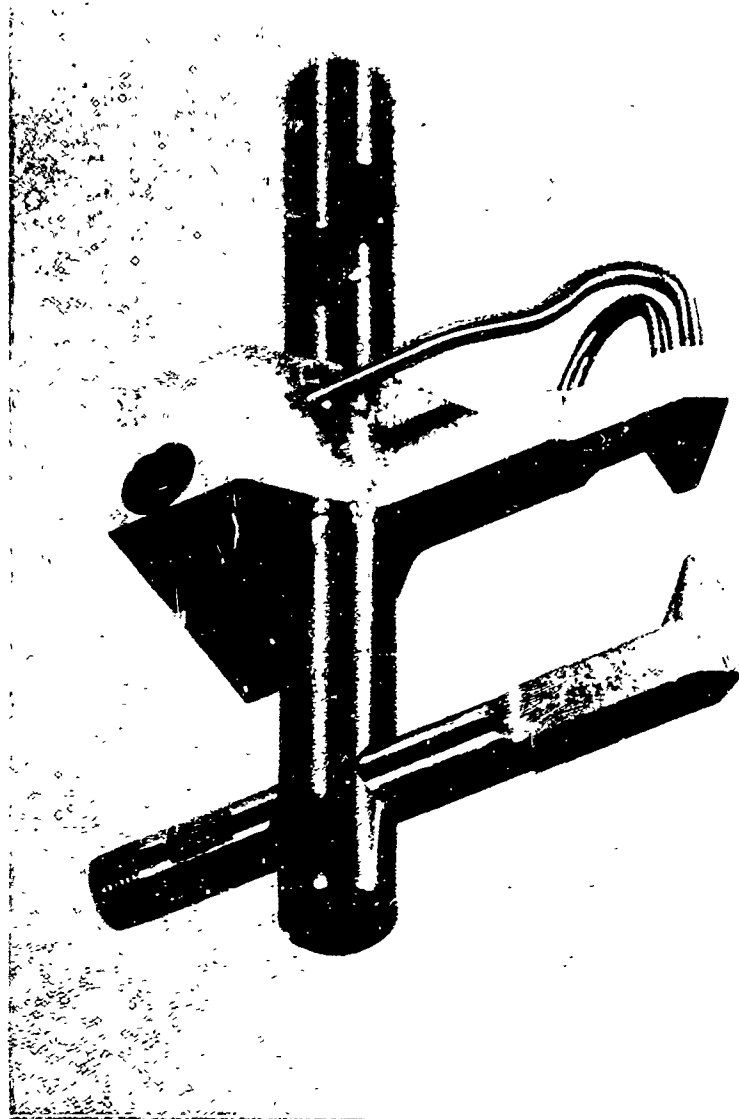
Installation of the fan is continuing on schedule. Present scheduling calls for completion of the facility in the Spring of 1969.

THE AERODYNAMICS OF PROPELLER-DRIVEN V/STOL LIFTING SYSTEMS

A detailed experimental study of the six components of force and moment acting on a tilted propeller and on a wing partially immersed in its slipstream. Results are being compared with various methods of theoretical prediction.

WIND TUNNEL WALL EFFECTS ON V/STOL MODELS

Investigation of the phenomena of "flow breakdown" with high-lift models in tunnels of different size and cross-section



FLUIDIC VELOCITY SENSOR HAVING
OUTPUT PRESSURE PROPORTIONAL
TO AIR VELOCITY FROM 0 TO 40 FT/SEC.

LOW SPEED AERODYNAMICS LABORATORY
NATIONAL AERONAUTICAL ESTABLISHMENT

shape with models located both on and off the tunnel centreline. Breakdown has been found to correlate with a model lift coefficient based on the tunnel cross-section area beneath the model span.

WIND TUNNEL SIMULATION OF SURFACE WIND STRUCTURE

Experimental comparison of grid and roughness methods of generating a thick boundary layer in tunnel test sections, similar in shear and turbulence characteristics to natural winds in the lower 2000 ft of the atmosphere.

FLUIDICS

A fluidic jet interaction anemometer, originally devised for low velocity measurements in air and water, is being further developed for rugged construction and for use over a wide velocity range.

HYBRID COMPUTER SIMULATION OF JET AIRCRAFT PERFORMANCE

Development of real time simulation of aircraft performance in three translational degree of freedom, in collaboration with Analysis Laboratory. Simulation includes steady and unsteady performance, engine thrust and fuel flow under full and part throttle operation.

LOW TEMPERATURE LABORATORY

LOW TEMPERATURE PROBLEMS IN RAILWAY OPERATIONS

Analytical and experimental work, conducted under the auspices of the Associate Committee on Railway Problems, Sub-Committee on Climatic Problems, including the low temperature performance of air brake systems, aftercooler design and development, an investigation into rail switch malfunctions under severe climatic conditions, evaluation of various rail switch heater systems, and refrigeration problems at low temperature. The heating of an insulated container for rail service has been investigated. Methods of cooling continuous welded rail to obtain a suitable temperature for rail laying and anchoring are being studied.

HELICOPTER DE-ICING

A study of helicopter icing protection involving the evaluation of various systems (thermal, fluid, and self-shedding materials) and the development of de-icing control systems including ice detectors.

ABSORPTION REFRIGERATION

The design and development of experimental prototype absorption refrigeration units based on the Platen-Munters cycle that requires no moving parts, with special reference to applications in remote areas and transportation.

AIRCRAFT INSTRUMENTATION

The investigation of possible modes of failure for aircraft pitot heads under icing and snow conditions.

FLUID AMPLIFIERS

An investigation of the operating characteristics of various models of turbulent reattachment fluid amplifiers to determine, primarily, the feasibility of applying the turbulent reattachment fluid amplifier to the direct control of high power fluid streams.

MISCELLANEOUS ICING INVESTIGATIONS

Analytical and experimental investigations of a non-routine nature, and the investigation of certain aspects of icing simulation and measurement.

TRAWLER ICING

In collaboration with the Department of Transport, an investigation of the icing of fishing trawlers and other vessels under conditions of freezing sea spray, and of methods of combatting the problem.

LOW TEMPERATURE APPLICATIONS IN MEDICAL ENGINEERING

The investigation (in co-operation with the Department of Neurosurgery, University of Ottawa) of selective brain cooling, and the development of medical engineering equipment allowing the quick connection of an in-line arterial heat exchanger.

The design, development, and evaluation of cannulae for temporary connections between arteries and extracorporeal blood circuits.

An investigation into boundary-layer thermal flow measurement in pulsatile non-Newtonian flow.

Design of a shunt valve for cerebrospinal fluid in hydrocephalus. The device can be adjusted after implantation without surgical intervention.

Development of a capsule for telemetry of intracranial pressure. A special feature is its permanent, radio-transparent, moisture-impermeable casing.

SHIP LABORATORY

CABLE FAIRINGS

Drag measurements made on various configurations.

HELICOPTER FLOATS

Models prepared for hydrodynamic force and moment measurements.

DUCTED PROPULSION

Propulsion tests carried out on a bulk carrier installation.

AIR CUSHION VEHICLES

Model tests commenced on a twin axial impeller rigid side wall combined lift and propulsion system.

CATAMARANS

Propulsion, manoeuvring, and seakeeping experiments with two models continued.

SHALLOW DRAFT FERRY

New manoeuvring devices fitted on a model and tests successfully completed.

STRUT-MOUNTED SUBMARINE VESSEL

Design and manufacture completed. Hovercraft installation trials nearing completion.

WEATHERSHIP SEAKEEPING

Various model anti-pitching fins and bulbs made ready for tests.

WAVE AND STRESS ANALYSIS

Further work was carried out in improving existing methods and developing new electronic and computer techniques. A number of sea records were processed.



HOVERCRAFT-MOUNTED ECHO SOUNDER SYSTEM
IN HANGAR AFTER TRIALS
SHIP LABORATORY
DIVISION OF MECHANICAL ENGINEERING

STRUCTURES AND MATERIALS LABORATORY

FATIGUE OF METALS

Fatigue strength of welded maraging steel plate; characteristics of structural grade steel bolt under fatigue loading; effects of environment on fatigue strength of light alloys; development of test methods for variable amplitude loads and investigation of effects of such loads; certification tests on aircraft components.

RESPONSE OF STRUCTURES TO HIGH INTENSITY NOISE

Study of excitation and structure response mechanisms; study of panel damping characteristics and critical response modes; investigation of fatigue damage laws; industrial hardware evaluation; investigation of jet exhaust noise.

HIGH TEMPERATURE AIRCRAFT HYDRAULICS

Study of bulk modulus of hydraulic fluids, including emulsions and mixtures in relation to temperature and pressure; studies of seal performance and high pressure, high velocity jet phenomena.

OPERATIONAL LOADS AND LIFE OF AIRCRAFT STRUCTURES

Instrumentation of aircraft for the measurement of flight loads and accelerations; fatigue life monitoring and analysis of load and acceleration spectra; full-scale fatigue spectrum testing of airframes and components, investigation of rough ground operations.

FRACTURE MECHANICS AND FRACTOLOGY

Investigation of crack formation and propagation in gradient stress fields; correlative electron microscope studies of fracture surfaces; notch sensitivity and fracture toughness; resistance of materials to high strain rate and impact loading.

RESEARCH ON PROTECTIVE COATINGS FOR REFRACTORY METALS

Investigation of coating compounds for protection of refractory metals at high temperatures; methods and techniques of coating deposition; study of interface diffusion rates and products; development of methods of evaluation of physical properties of coated test coupons.

MECHANICS AND THEORY OF STRUCTURES

Preparation of formulae and charts for vibrations of an elastically suspended rigid body; study of coupled flexural-torsional vibration of a uniform cantilever beam, development of transmission matrices, extension of beam theory to include effects of transverse curvature; study of dynamics of a cable under transverse impact.

CONSTRUCTION AND DEVELOPMENT OF FLIGHT IMPACT SIMULATOR

Development of Canadian facility; analysis of national needs and co-ordination of utilization, hardware evaluations.

CALIBRATION AND CERTIFICATION OF FORCE MEASURING DEVICES

Facilities available for the calibration of government, university, and industrial equipment include deadweight force standards up to 100,000 lb, back-to-back calibration of accelerometers, and limited calibration of fluid pressure-type transducers.

COMPOSITE AND NON-METALLIC MATERIALS

Studies of resins, crosslinking compounds, and polymerization initiators, material properties and uses of polymers and reinforcements for composites; procedures for application and fabrication; structural efficiencies.

FINITE ELEMENT METHODS

Development of refined finite elements for plate bending and plane stress, development and application of a cylindrical shell finite element; application of finite elements to flutter problems, development of a general triangular shell element.

UNSTEADY AERODYNAMICS LABORATORY

STUDY OF VISCOUS HYPERSONIC FLOW ON A STEADY PLATE

Surface pressure distributions and flow field surveys at hypersonic Mach numbers on a flat plate at incidence, including the use of anemometry and glow-discharge techniques.

STUDY OF OSCILLATORY PHENOMENA IN HYPERSONIC FLOW

Theoretical and experimental investigation of the effects of viscosity and leading-edge bluntness on aerodynamic characteristics of two-dimensional oscillating airfoils. Pressure distribution and flow field measurements, determination of static and dynamic stability derivatives, optical studies. All experiments performed in helium at Mach numbers 9 and 18.

HELIUM HYPERSONIC WIND TUNNEL

Two 11-inch diameter contoured nozzles (on long term loan from the U.S.) for Mach numbers 10 and 18 now available. Also available, a heater to provide small (100°F) increases in the stagnation temperature of the flow.

INVISCID HYPERSONIC FLOW OVER AN OSCILLATING WEDGE

Analytical study of the inviscid flow field over a wedge oscillating with an amplitude of the same order as wedge semi-angle. Solution of the resulting non-linear equation using a perturbation technique valid for small frequencies of oscillation.

SLENDER BODIES WITH "SQUARE" FLARE

Experiments at Mach number 9 in helium on the aerodynamic characteristics of slender cone-cylinder configurations with conical and "square" flares.

GAS PHASE REACTION KINETICS

A physico-chemical study of the reactions of some constituents of the upper atmosphere, such as oxygen, nitrogen, and hydrogen atoms, to provide laboratory data in support of rocket experiments on upper atmospheric composition. Proposal available for a new method for the absolute determination of the atomic concentration of oxygen and nitrogen in the 90-120 km region.

OPTICAL AMPLITUDE-METER

New optical technique for accurate remote determination of local angular amplitude of objects performing harmonic oscillation.

USE OF FREE FLYING MODELS IN WIND TUNNEL

Further development of the above technique including improvements in (a) model release method, (b) test section flow conditions, (c) accuracy of data read-out from high-speed film and (d) computer program for data processing.

FM TELEMETRY ON FREE FLYING MODELS

Development of a miniature FM telemeter and of a miniature capacitive differential pressure transducer to measure base pressure on free-flying models in the hypersonic wind tunnel.

USE OF FLUORESCENT TRACERS IN LOW-FLYING AERIAL SPRAYING

Evaluation of the photometric feasibility of a technique based on the addition of fluorescent compounds to the spray and irradiation with an airborne ultraviolet light source to provide on-board indication of the sprayed areas.

PUBLICATIONS

MISCELLANEOUS PAPERS

- BUCK, L. Designing Displays for Process Control Operators. Canadian Controls and Instrumentation, Vol. 7, No. 12, December 1968.
- ELIAS, L. Evaluation of a Proposal for the Use of Fluorescent Additives as Tracers for Aerial Spraying Operations. NRC, NAE Laboratory Technical Report, LTR-UA-2, September 1968.
- FOWLER, H.S. and DEBLOIS, J. NRC Movie No. 16 "Magic Carpet - A Progress Report on Ground Effect Machines in Canada", December 1968.
- GODBY, E.A., HOOD, P.J.* and BOWER, M.* Magnetic Surveys in Hudson Bay - 1965 Oceanographic Project. Presented at Earth Science Symposium on Hudson Bay, Ottawa, February 1968.
- GODBY, E.A., HOOD, P.J.* and BOWER, M.* Aeromagnetic Profiles Across the Reykjanes Ridge Southwest of Iceland. Journal of Geophysical Research, Vol. 73, No. 24, 15 December 1968.
- KACPRZYNSKI, J.J. A Low Frequency Solution of Unsteady Inviscid Hypersonic Flow Past an Oscillating Wedge with Attached Shock Wave. NRC, NAE Laboratory Technical Report, LTR-UA-5, September 1968.
- KACPRZYNSKI, J.J. Large Amplitude Harmonic Oscillations of a Thick Wedge with Attached Shock Wave in Inviscid Hypersonic Flow. NRC, NAE Laboratory Technical Report, LTR-UA-6, October 1968.
- KRISHNAPPA, G. Shear Noise Source Terms for a Circular Jet. To be published in Journal of Applied Mechanics, ASME Trans.
- KRISHNAPPA, G. and CSANADY, G.T. An Experimental Investigation of the Composition of Jet Noise. To be published in the Journal of Fluid Mechanics.
- KUIKEN, H.K. Large Amplitude Low Frequency Oscillation of a Slender Wedge in Inviscid Hypersonic Flow. NRC, NAE Laboratory Technical Report, LTR-UA-4, September 1968.
- LABERGE, J.G. and ORLIK-RUCKEMANN, K.J. Preliminary Dynamic Stability Results for Slender Wedges at Mach 9 and 18 in Helium. NRC, NAE Laboratory Technical Report, LTR-UA-3, September 1968.
- LARKIN, B.S. Evaluation of Heat Exchanger Surfaces for Use in Gas Turbine Cycles. Presented to ASME Winter Annual Meeting, December 1968.
- MILNER, M. A Neuromuscular Oscillator. To be published in the South African Journal of Science.
- OLSON, M.D., KOSKO, E., LINDBERG, G.M. and COWPER, G.R. Formulation of a New Triangular Plate Bending Element. Published in CASI Transactions, Vol. 1, No. 2, September 1968, pp. 86-90.
- OLSON, M.D. and LINDBERG, G.M. Vibration Analysis of Cantilevered Plates Using a New Cylindrical Shell Finite Element. Presented at the Air Force Second Conference on Matrix Methods in Structural Mechanics, Dayton, Ohio, 15-17 October 1968. To be published in Proceedings.
- RAINBIRD, W.J. Turbulent Boundary-Layer Growth and Separation on a Yawed Cone. AIAA Journal, Vol. 6, No. 12, December 1968.
- SCHAUB, U.W. Experimental Investigation of Flow Distortion in Fan-in-Wing Inlets. AIAA Journal of Aircraft, Vol. 5, No. 5, September - October 1968.
- SMITH, F.W. La Mécanique des Milieux Continus et la Chimie Physique des Liquides; Etude de Contraintes Normales se Produisant dans les Liquides à Structure Simple. Cahiers du Groupe Français de Rhéologie, No. 6, 1968, pp. 341-344.
- TANNER, J.A. and ROMERO-SIERRA, C. Microwaves Vs Birds-Effects on Feeding Behavior. Presented at the 21st Annual Conference on Engineering in Medicine and Biology, Houston, Texas, 18-21 November 1968. Published in Conference Proceedings.
- WOODSIDE, C.M. A Statistical Equivalence Between Stochastic and Non-Linear Systems. (in Russian). To be published by *Avtomatika i Telemekhanika*, Moscow.
- WOODSIDE, C.M. Dimensional Analysis in Economic Systems. To be published by *Ekonomicheskii i Matematicheski Metodi*, Moscow.
- WOODSIDE, C.M. The Conjugate Gradient Method for Optimal Control Problems with Bounded Control Variables. To be published by *Avtomatika*.
- WOODSIDE, C.M. The Design of Optimal Extremal Controllers. International Journal of Control, Vol. 8, No. 6, December 1968.

UNPUBLISHED PAPERS AND LECTURES

- ADAMS, P.A. A Device for Remote Determination of Oscillation Amplitude. Presented at the 30th Meeting of the Supersonic Tunnel Association, October 1968.
- BAKER, R. Airborne Aeromagnetic and Infrared Research being Conducted at the National Aeronautical Establishment. Presented at Symposiums at University of Victoria and at University of British Columbia, December 1966.
- BUCK, L. Psychological Stress and Step Input Tracking. Presented to Human Factors Association of Canada, 5 December 1968.
- BUCK, L. Experiments on Railway Vigilance. Presented to Human Factors Association of Canada, 5 December 1968.
- CAIGER, B. Flight Recorders for Accident and Incident Investigation. Presented at D.O.T. Accident Investigation Symposium, Ottawa, 28 November 1966.
- DICK, T.M. Comments on the Computation of Wave Forces on a Vertical Wall Breakwater. Presented at Second Marine Engineering Seminar, Ottawa, December 1968.
- FEIR, J.E. The Instability of Progressive Waves on Deep Water. Presented at Seminar at the University of Waterloo, Waterloo, Ontario, October 1968.
- GODBY, E.A., HOOD, P.J.* and BOWER, M.* Aeromagnetic Reconnaissance of the Mid-Atlantic Ridge South of Iceland. Presented at Annual Congress, Canadian Association of Physicists, Calgary, June 1968.
- GODBY, E.A., HOOD, P.J.* and BOWER, M.* Aeromagnetic Profiles Across the Reykjanes Ridge Southwest of Iceland. Presented at IAGA - WMS Symposium, "Description of the Earth's Magnetic Field", National Academy of Sciences, Washington, D.C., 22-25 October 1968.
- GODBY, E.A. Recent Developments in M.A.D. Systems. Presented at 20th Defence Research Board Symposium, Ottawa, 20 November 1968.
- INCE, S. Canadian Research on the Great Lakes. Presented at Institute of Water Resources Seminar, University of Connecticut, Storrs, Conn., November 1968.
- KASVAND, T. Recognition of Nerve Fiber Cross-Sections. Presented at Summer School on "Automatic Interpretation and Classification of Images". Nato Advanced Study Institute Program, Pisa, Italy, 26 August - 7 September 1968.
- KASVAND, T. Pattern Recognition. Presented to Electrical Engineering Department, Carleton University, Ottawa, 22 November 1968.
- KASVAND, T. Recognition of Nerve Fiber Cross Sections, Water Droplets and other Blob-Like Objects. Presented at Computer Science Center, University of Maryland, 9 December 1968.
- OHMAN, L.H. and RAINBIRD, W.J. Reynolds Number Capabilities of the NAE 5' x 5' Blowdown Wind Tunnel with a Two-Dimensional Transonic Insert. Presented at the 30th Semi-Annual Meeting of the Supersonic Tunnel Association, Columbus, Ohio, 3, 4 October 1968.
- OLSON, M.D. Supersonic Flutter of Circular Cylindrical Shells. Presented to Graduate Student Seminar, Dept. of Civil Engineering, University of Waterloo, Waterloo, Ont., 28 November 1968.
- ORLIK-RÜCKEMANN, K.J. On Dynamic Boundary Layer Interactions. Seminar given at NASA Ames Research Center, 11 December 1968.
- PELLEG, J. Diffusion of ^{51}Cr Into Niobium Single Crystals. Presented at AIME Annual Conference, Detroit, Michigan, 15 October 1968.
- PELLEG, J. Diffusion of ^{51}Cr Into Polycrystalline Niobium. Presented at AIME Annual Conference, Detroit, Michigan, 15 October 1968.
- PLOEG, J. A General Discussion on the Selection of a Design Wave. Presented at Second Engineering Marine Seminar, Ottawa, December 1968.
- STRUGNER, P.L. Engine Oil Classification and Oil Change Periods. Presented at the Fifth Annual Canadian Fleet Maintenance Seminar of the Automotive Transportation Service Superintendents' Association, Toronto, 25 September 1968.
- WIEBE, W. The Use of Electron Fractography in Failure Analysis. Presented at Failure Analysis Symposium, Aircraft Accident Investigation Division, Dept. of Transport, Ottawa, 25-29 November 1968.
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AERONAUTICAL LIBRARY

Statistical Summary of Library Operations for the Quarter October - December 1968

Documents accessioned (including duplicates)	3,272
Documents accessioned (first copies only)	2,562
Cards added to the catalogue	13,897
Books received	422
Bound periodicals received.....	73
Loans to NRC staff (including Periodical circulation and Xerox and Microfiche copies supplied in lieu of loans).....	8,041
Loans and distribution to outsiders.....	2,090
Total circulation.....	10,131

Statistical Summary for 1967 and 1968

	<u>1967</u>	<u>1968</u>
Documents accessioned (including duplicates)	14,337	15,268
Documents accessioned (first copies only)	11,195	11,461
Cards added to the catalogue	64,075	62,853
Books received	1,454	1,557
Bound periodicals received.....	483	337
Loans to NRC staff (including Periodical circulation and Xerox and Microfiche copies supplied in lieu of loans).....	28,122	30,505
Loans and distribution to outsiders.....	7,057	7,648
Total circulation.....	35,179	38,153

NOTE: These summaries include statistics for the Uplands Branch of the Aeronautical Library.

PROPRIETARY PROJECTS DURING 1967

Part of the work of the two Divisions covers proprietary projects, and, for this reason, has not been reported in these Bulletins.

Following is a list of Industrial Organizations, Government Departments and Universities for whom work was done during 1968.

INDUSTRIAL ORGANIZATIONS

Aero Photo Inc., Quebec, P.Q.
Aeroplane and Armament Experimental Establishment, Boscombe Down, England
Air Canada, Dorval, P.Q.
American Society for Testing Materials, Philadelphia, Pa., U.S.A.
Amoco Chemical Corp., Chicago, Ill., U.S.A.
Amoco Chemical Corp., Whiting, Indiana, U.S.A.
Associated Designers and Inspectors, Fredericton, N.B.
Atomic Energy of Canada Ltd., South March, Ont.
Avian Aircraft Ltd., Georgetown, Ont.
Aviation Electric Ltd., Montreal, P.Q.

Babcock-Wilcox Canada Ltd., Galt, Ont.
Bach-Simpson Ltd., London, Ont.
Barnes Engineering Co., Stamford, Conn., U.S.A.
Bell Helicopter Co., Fort Worth, Texas, U.S.A.
Bobtex Corporation, Montreal, P.Q.
Boeing Co., Vertol Division, Morton, Pa., U.S.A.
Boeing of Canada Ltd., Arnprior, Ont.
Bond Beverages Ltd., Grand Falls, Nfld.
Bourns (Canada) Ltd., Toronto, Ont.
Bristol Aerospace Ltd., Winnipeg, Man.
Bristow Instruments Co., Edmonton, Alta.
British American Research & Development Co., Sheridan Park, Ont.
B.P. Canada Ltd., Oakville, Ont.
B.P. Canada Ltd., Montreal, P.Q.
Burrard Dry Dock Co., Ltd., Vancouver, B.C.

CAMAT Transportation Consultants Inc., Montreal, P.Q.
G.T.R. Campbell, Montreal, P.Q.
Canadair Ltd., Montreal, P.Q.
Canadian Aero Services Ltd., Ottawa, Ont.
Canadian Aniline & Extract Co., Hamilton, Ont.

Canadian Amateur Skiing Association, Toronto, Ont.
Canadian Flight Equipment Co., Ltd., Trenton, Ont.
Canadian General Electric, Port Hawkesbury, N.B.
Canadian General Electric, Scarborough, Ont.
Canadian Ice Machine Co., Toronto, Ont.
Canadian International Paper Co., Gatineau, P.Q.
Canadian National Railways, Montreal, P.Q.
Canadian National Transportation Ltd., Toronto, Ont.
Canadian Owners & Pilots Ass'n., Ottawa, Ont.
Canadian Pacific Railway Co., Montreal, P.Q.
Canadian Petrofina Co., Pointe-Aux-Trembles, P.Q.
Canadian Vickers Ltd., Montreal, P.Q.
Canadian Westinghouse Co., Ltd., Hamilton, Ont.
Capital Air Surveys Ltd., Ottawa, Ont.
Castrol Limited, Bracknell, Berkshire, England
Champlain Power Products Ltd., Rexdale, Ont.
Chevron Chemical Co., Oronite Div., San Francisco, California, U.S.A.
Commercial Marine Services, Montreal, P.Q.
Computing Devices of Canada, Bell's Corners, Ont.
Consolidated Bathurst Ltd., Woodlands Div., Portage du Fort, P.Q.
Cook Electric Company, Chicago, Ill., U.S.A.
Co-ordinating Research Council, New York, N.Y., U.S.A.
Cornell Aeronautical Laboratories, Inc., Buffalo, N.Y., U.S.A.
Cuthbertson and Cassian Ltd., Port Credit, Ont.

Davie Shipbuilding Ltd., Levis, P.Q.
De Havilland Aircraft of Canada Ltd., Downsview, Ont.
Dominion Engineering Works Ltd., Montreal, P.Q.
DOSCO Industries Ltd., Halifax, N.S.
Dow Corning Corp., Midland, Mich., U.S.A.

Eastern Air Lines Inc., New York, N.Y., U.S.A.
Eastern Provincial Airways (1963) Ltd., Gander, Nfld.
Emery Corp., Cincinnati, Ohio, U.S.A.
Enjay Additives Laboratory, Linden, N.J., U.S.A.
Esso Research and Engineering, Linden, N.J., U.S.A.
Eutectic Welding Ltd., Pointe Claire, P.Q.

Federal Equipment, Ottawa, Ont.
Ferranti-Packard Electric Ltd., Toronto, Ont.
Field Aviation, Malton, Ont.
Fleet Mfg. Ltd., Fort Erie, Ont.

Found Bros. Aviation Ltd., Grand Bend, Ont.

Gendron et Lefebvre, Laval, P.Q.

German and Milne, Montreal, P.Q.

Golden Eagle Can. Ltd., Montreal, P.Q.

Goodyear Tire & Rubber Co., Akron, Ohio, U.S.A.

Graham F. Crate Ltd., Ottawa, Ont.

Great Can. Oil Sands, Fort McMurray, Alta.

Hale and Associates Ltd., Port Credit, Ont.

Harvey Vale Enterprises, Montreal, P.Q.

Hauts-Monts Inc., Quebec, P.Q.

Mr. R. Holmes, Nanotick, Ont.

Howard & Sons (Can) Ltd., Cornwall, Ont.

Huyck Canada Ltd., Arnprior, Ont.

Ian Martin Associates, Ltd., Ottawa, Ont.

Imperial Oil Ltd., Toronto, Ont.

Imperial Oil Enterprises Ltd., Dartmouth, N.S.

Imperial Oil Enterprises Ltd., Montreal, P.Q.

Imperial Oil Enterprises Ltd., Sarnia, Ont.

Ingersoll-Rand Co., Ltd., Sherbrooke, P.Q.

Iron Ore Company of Canada, Labrador City, Nfld.

Irving Refinery Ltd., St. John, N. J.

J.P. Sharp Associates, Ottawa, Ont.

Jeffrey Manufacturing Co., Ltd., Montreal, P.Q.

Jet Auto Wash, Ottawa, Ont.

Johnson, Matthey and Mallory Ltd., Toronto, Ont.

Kenting Aviation Ltd., Malton, Ont.

Keystone Lubricating Co., Scarborough, Ont.

Ladouceur's Garage, Alexandria, Ont.

Laurentide Aviation Ltd., Montreal, P.Q.

Leigh Instruments Limited, Carleton Place, Ont.

Levy Auto Parts, Toronto, Ont.

Litton Industries Limited, Toronto, Ont.

Lloyd's Register of Shipping, Montreal, P.Q.

Lockheed Aircraft Corp., Burbank, Calif., U.S.A.

Lockwood Survey Corp., Ltd., Toronto, Ont.

Lockwood Survey Corp., Ltd., Vancouver, B.C.

Lubrizol Corp., Don Mills, Ont.

Lubrizol Corp., Cleveland, Ohio, U.S.A.

Mohawk Indian Band, Caughnawaga Reserve (Trap Factory), P.Q.

Monsanto Co., St. Louis, Missouri, U.S.A.

Montreal Transportation Commission, Montreal, P.Q.

Morrison, Hershfield, Millman & Huggins Ltd., Toronto, Ont.

National Center for Atmospheric Research, Boulder, Colorado, U.S.A.

Nemo Brier Ltd., Hull, P.Q.

Noranda Mines Limited, Toronto, Ont.

Noranda Copper Refining Industries Ltd., Montreal, P.Q.

Nordair Limited, Dorval, P.Q.

Northumberland Consultants Ltd., Montreal, P.Q.

John A. Nysten, Fort Lauderdale, Florida, U.S.A.

Orenda Ltd., Toronto International Airport, Ont.

Ottawa Transportation Commission, Ottawa, Ont.

Personal Plane Services Ltd., Ottawa, Ont.

Phillips Electronics Industries Ltd., Toronto, Ont.

Photographic Surveys Inc., Montreal, P.Q.

Pioneer Chain Saws, Peterborough, Ont.

Polyfiber Limited, Renfrew, Ont.

Port Weller Dry Docks Ltd., St. Catharines, Ont.

Preci-Tools Limited, Montreal, P.Q.

Pyrene Manufacturing Company of Canada Ltd., Toronto, Ont.

Quebec Hardwoods Inc., Hull, P.Q.

Quebec North Shore & Labrador Railway Co., Sept Iles, P.Q.

Rails Company, New Jersey, U.S.A.

Range Aerial Survey Ltd., Calgary, Alta.

Renfrew Electric Co., Ltd., Renfrew, Ont.

Robert Mitchell Co., Ltd., Montreal, P.Q.

Rolls Royce (Montreal) Limited, Montreal, P.Q.

Rolls-Royce Ltd., Derby, England

Saguenay Terminals Limited, Arvida, P.Q.

Sandia Corporation, Albuquerque, New Mexico, U.S.A.

Schofield & de Vries, Breslau, Ont.

Separator Engineering Ltd., Montreal, P.Q.

Shell Canada Ltd., Montreal, P.Q.

Shell Canada Ltd., St. Boniface, Man.

Shell Canada Ltd., Toronto, Ont.

Shell Canada Ltd., Vancouver, B.C.

Spartan Air Services Ltd., Ottawa, Ont.

Spratt Sand & Gravel, Ottawa, Ont.
Sperry Gyroscope Co. of Canada Ltd., Montreal, P.Q.
Steel Company of Canada, Hamilton, Ont.
Structo Design & Development Corp., Ottawa, Ont.
Sud Aviation, France
Sun Oil Canada Ltd., Toronto, Ont.
Superior Propane Ltd., Don Mills, Ont.
Survair Limited, Ottawa, Ont.
Sutton Perry Ltd., Ottawa, Ont.
Swan and Wooster - CBA, Vancouver, B.C.

Tamco Ltd., La Salle, Ont.
J. Dale Taylor, Prince Rupert, B.C.
Terra Surveys Limited, Ottawa, Ont.
Terry Industries Limited, Dorval, P.Q.
Texaco Canada Ltd., Montreal, P.Q.
Trans Canada Pipe Lines, Toronto, Ont.
Tremblay, Mr. Maurice, Ottawa, Ont.
Turbo Chemical Co., Edmonton, Alta.

Underwriters Laboratories of Canada Ltd., Scarboro, Ont.
Union Carbide Can. Ltd., Montreal East, P.Q.
United Aircraft of Canada Ltd., Longueuil, P.Q.
Upper Lakes Shipping Ltd., Toronto, Ont.

Valeriot Electronics (Guelph) Ltd., Guelph, Ont.
Vapor Heating Co. of Canada, Montreal, P.Q.
Verreault Navigation Inc., Cte. Matane, P.Q.
Victoria Hospital, Renfrew, Ont.

Williams Research Corporation, Walled Lake, Michigan, U.S.A.

GOVERNMENT DEPARTMENTS

Admiralty Experiment Works, Hants, England
Atomic Energy of Canada, Winnipeg, Man.

The British Ship Research Association, Wallsend, England

Canada Centre for Inland Waters, Burlington, Ont.
Canadian Government Specifications Board, Ottawa, Ont.
Corporation of the City of Ottawa, Ottawa, Ont.

Defence Research Board, CARDE, Valcartier, P.Q.

Defence Research Board, CARDE, Ottawa, Ont.
Defence Research Board, Naval Research Laboratories, Halifax, N.S.
Defence Research Establishment, Atlantic, Halifax, N.S.
Department of Agriculture, Ottawa, Ont.
Department of Consumer Affairs, Ottawa, Ont.
Department of Defence Production, Ottawa, Ont.
Department of Energy, Mines & Resources, Ottawa, Ont.
Department of Energy, Mines & Resources, Burlington, Ont.
Department of Forestry and Rural Development, Ottawa, Ont.
Department of Indian Affairs and Northern Development, Ottawa, Ont.
Department of Industry, Ottawa, Ont.
Department of Lands and Forests, Province of Ontario, Port Arthur, Ont.
Department of National Defence (AIR), Ottawa, Ont.
Department of National Defence (ARMY), Ottawa, Ont.
Department of National Defence (NAVY), Ottawa, Ont.
Department of Public Works, Ottawa, Ont.
Department of Trade and Commerce, Ottawa, Ont.
Department of Transport, Air Services, Ottawa, Ont.
Department of Transport, Marine Services, Ottawa, Ont.
Department of Transport, Prescott, Ont.
Directorate of Maritime Engrg., Ships, Ottawa, Ont.

Environmental Science Services Administration, Washington, D.C., U.S.A.

Federal Aviation Agency, Washington, D.C., U.S.A.
Forest Products Laboratories, Ottawa, Ont.

Hydro-Quebec, Montreal, P.Q.

National Film Board, Ottawa, Ont.
National Physical Laboratory, Feltham, Middlesex, England
National Printing Bureau, Hull, P.Q.
National Severe Storms Laboratory, Norman, Oklahoma, U.S.A.
Naval Ship Research and Development Center, Washington, D.C., U.S.A.
Netherlands Ship Model Basin, Holland

Ontario Dept. of Lands and Forests, Toronto, Ont.

Royal Aircraft Establishment, Bedford, England
Royal Canadian Mounted Police, Ottawa, Ont.

Saskatchewan Research Council, Sask.

United States Air Force, Washington, D.C., U.S.A.

United States Coast Guard, Washington, D.C., U.S.A.

United States Navy, Washington, D.C., U.S.A.

UNIVERSITIES

Carleton University, Ottawa, Ont.

Laval University, Quebec, P.Q.

McGill University, Montreal, P.Q.

Memorial University of St. John's, Nfld.

Queen's University, Kingston, Ont.

Queens University, Belfast, Northern Ireland

University of Alberta, Edmonton, Alta.

University of Ottawa, Ottawa, Ont.

University of Toronto, Toronto, Ont.

University of Western Ontario, London, Ont.